

Publication 5002

AGRICULTURAL MATERIALS HANDLING MANUAL

PART 6 STORAGE FACILITIES


SECTION 6.2

TYPES OF STORAGES

630.4
C212
P 5002
sect. 6.2
1979
c.2



**Agriculture
Canada**



Digitized by the Internet Archive
in 2012 with funding from
Agriculture and Agri-Food Canada – Agriculture et Agroalimentaire Canada

AGRICULTURAL MATERIALS HANDLING MANUAL

PART 6 STORAGE FACILITIES

SECTION 6.2

TYPES OF STORAGES

The Agricultural Materials Handling Manual is produced in several parts as a guide to designers of materials handling systems for farms and associated industries. Sections deal with selection and design of specific types of equipment for materials handling and processing. Items may be required to function independently or as components of a system. The design of a complete system may require information from several sections of the manual.

J. POS
ONTARIO AGRICULTURAL COLLEGE
UNIVERSITY OF GUELPH
GUELPH, ONT.

PREPARED FOR THE CANADA COMMITTEE
ON AGRICULTURAL ENGINEERING SERVICES
OF
CANADIAN AGRICULTURAL SERVICES
COORDINATING COMMITTEE

PUBLICATION 5002, available from
Information Services, Agriculture Canada, Ottawa K1A 0C7

©Minister of Supply and Services Canada 1980
Cat. No. A21-12/6-2/1980E ISBN: 0-662-11098-6
Printed 1980 1.5M-10:80

TABLE OF CONTENTS

6.2.1	Introduction	4	6.2.4	Processed Feeds and Concentrates	22
6.2.2	Small Grains and Shelled Corn	4	6.2.4.1	Plywood Bulk Bins	22
6.2.2.1	Planning Grain Handling Storage Systems	5		Wood-framed Rectangular Plywood Bins	22
6.2.2.2	Cylindrical Grain Bins	6		Finger-jointed Plywood Bins	23
	Foundations for Cylindrical Grain Bins	6	6.2.4.2	Manufactured Steel Bins	23
	Cylindrical Galvanized Steel Bins	6	6.2.5	Forages and Bedding	23
	Circular Bin Arrangement for Grain Storage	7	6.2.5.1	Vertical Silage Storage	23
	Cylindrical Plywood Bins	9		Storage Losses	23
	Joint Design for Cylindrical Plywood Grain Bins	9		Design Criteria	24
	Cylindrical Fiberglass Bins	11		Reinforced Extended-ring Foundation	25
6.2.2.3	Rectangular Wood Bins	11		Selection of Required Silo Dimensions	28
	Rectangular Plywood Grain Bins	11		Oxygen-limiting Silos	29
	Rectangular Grain Bins, Cribbed Construction	11	6.2.5.2	Horizontal Silage Storage	30
6.2.2.4	Rectangular Horizontal Grain Storage	12		Storage Losses	30
6.2.2.5	Vertical Silos for Grain Storage	12		Dimensional Requirements	30
	Loads Imposed by Stored Grain	12		Horizontal Pressure Characteristics	30
6.2.2.6	High-moisture Grain Storage	14		Typical Horizontal Silos	30
	High-moisture Grain Storage in Concrete Silos	14		Pre-cast Horizontal Silos	32
	High-moisture Grain Storage in Steel Bins	17		Self-feeding Gates for Horizontal Silos	33
	High-moisture Grain Storage in Gas-tight Steel Silos	17	6.2.6	Farm Machinery Storage	34
6.2.3	Ventilated-crib Ear Corn Storage	20		Location and Orientation	34
6.2.3.1	Pressure Characteristics and Limiting Dimensions for Ear Corn Storage	20		Space Requirements	34
6.2.3.2	Types of Ear Corn Storages	20		Building Type	34
	Temporary Snow-fence Cribs	20		Fire Prevention	34
	Bent-strip Hardwood Cribs	20		Ventilation	34
				Electrical	34
				Doors	35
				Floors	35
			6.2.7	Manure Storage	35
			6.2.8	References	38

SECTION 6.2 TYPES AND STORAGES

6.2.1 INTRODUCTION

Many agricultural products and by-products are stored on the farm such as home-grown and commercial feeds, fruits and vegetables, fertilizers and manure. The functional requirements for the storage of these products and the important material properties are presented in Sections 6.1 and 7.1, respectively. Detailed working drawings for livestock production buildings and storages can be obtained from the Canada Plan Service through provincial Agricultural Extension Offices.

This section will deal mainly with storage related to feed handling systems — grains, processed feeds, silages and roughages — as well as manure handling facilities. Storages for other agricultural materials will be included in future revisions as the information becomes available.

6.2.2 SMALL GRAINS AND SHELLS CORN

Grain may be stored on the farm for several reasons; either as seed for the next season's crop, as feed for livestock, or to wait for more favorable market conditions.

Only clean, dry grain should be placed in storage, unless drying and cleaning methods are planned as part of the storage system. Cracked grain, screenings, chaff, dust and poor ventilation can be expected to cause trouble. Even clean, dry grain requires frequent inspections for mold, insects, leaks, and high humidity.

Grain is usually stored in tight metal, wood and concrete containers. If it is to be stored for 1 year or more, 13% moisture content is considered safe for most grains; soybeans should be stored at 11% and barley at 12%. If grain is to be stored for seed, the moisture content should be 2% lower. When grains other than soybeans are stored for feed processing during the first winter, the moisture content can be 15 to 16% without too much danger. However, feed prepared under these conditions should be used promptly, since the heat produced by processing can initiate mold growth, resulting in stale feed.

Little care is required to maintain the quality of dry grain in storage if the facilities are properly designed. Properly designed and properly constructed grain storages should:

1. exclude all outside moisture from rain, snow and ground contact.
2. contain the grain without leakage, and resist the destructive forces of wind, snow and internal grain pressures on walls and floors.
3. permit fumigation for control of grain insects.
4. exclude rodents and birds.
5. provide sufficient space to properly ventilate for the removal of heat and moisture.
6. permit access for convenient loading, inspection and unloading of stored grain.

In addition, grain bins are frequently used for drying grain. For this purpose, the bin floor is perforated and supported above an air plenum chamber.

Even when grain is stored at "safe" moisture levels, redistribution of moisture in bins has been observed (9)¹.

This moisture migration has been attributed to temperature variations within the grain mass. During the autumn cooling-down period, grain at the bin center remains warmer than grain at the top and perimeter. Warmer air from the center rises by convection. This air, in contact with cooler grain at the top center of the mass, is cooled, and moisture is released to the grain in this area.

Moisture increase can be sufficient to spoil the grain under some conditions.

Moisture migration is controlled in storage by blowing or sucking cool dry air through the bin, or by mechanically turning the grain over to redistribute the heat and moisture. Figures 6.2.1 and 6.2.2 illustrate two types of fan aerators used in prefabricated steel grain tanks for this purpose. Where bin-floor drying systems are used, the motor and fan used for drying is later used for bin aeration; the fan has much more capacity than is actually required, since the time for adequate aeration is reduced.

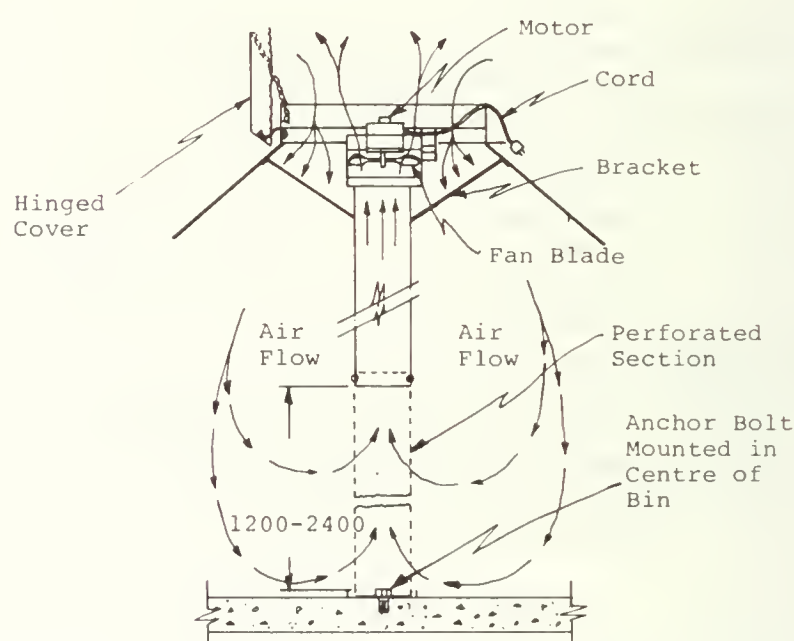


Figure 6.2.1 Cutaway section showing floor anchor, tubes and fan installation.

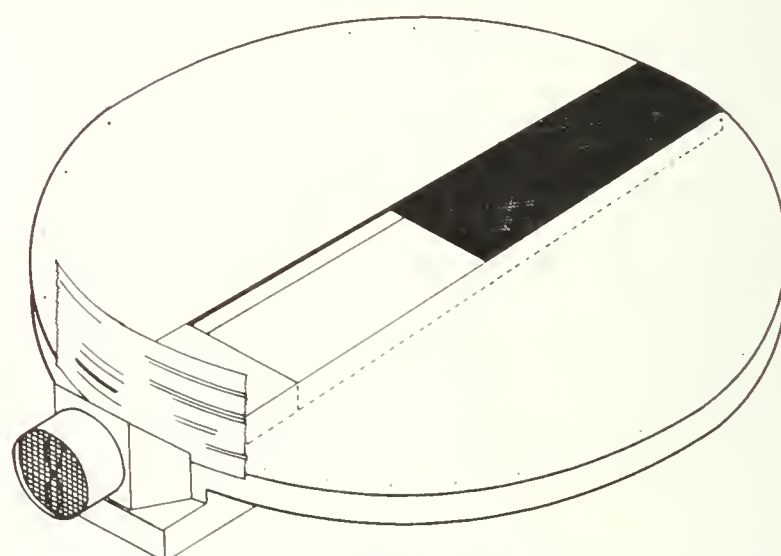


Figure 6.2.2 Concrete slab for circular grain bins, showing fan aeration system built into the floor. Center trough may also be used for unloading grain.

For aeration, suction fans that exhaust air to outdoors are preferred over pressure fans; pressure aeration could cause condensation in poorly ventilated spaces between the grain and the roof.

¹Numbers in brackets refer to References, 6.2.8

Rates of air flow recommended vary from 0.5 to 3.0 L/(s·m³); 1.2 L/(s·m³) is common. The U.S.D.A. (2) states that a fan operated at 1.2 L/s will cool stored grain to ambient air temperature in about 80 hours in summer, 120 hours in fall, and 160 hours in winter. Assuming that aeration is possible for an average of 10 hours per day, 12 days would be required in the fall. Cooling time for other rates is inversely proportional to the flow. Table 6.2.1 gives convenient data for selection of grain aeration equipment (34).

Aeration during periods of high humidity can increase the moisture content of dry grain. Table 6.2.2 is a guide to operation of aeration and drying equipment. Humidity-operated controls are recommended for automatic aeration.

6.2.2.1 Planning Grain Handling Storage Systems

As the volume of grain produced is increased, the need for careful planning and organization becomes more important. One of the basic principles of materials handling is to make flow continuous. Organized continuous flow in a grain handling system usually means a closed handling loop. A simple closed handling loop consists of a grade dump to an elevating conveyor with a spout for gravity flow to a storage bin and a bin unloader back to the grade dump. This basic closed handling loop can be expanded to include several loops around the grade dump and vertical elevator.

For small operations of less than 700 m³ storage, portable inclined conveyors can be used to move grain into storage; this single piece of equipment, easily moved to different

locations, is very convenient. As the size of operations increase, portable equipment must not only become too large for easy handling, but it can no longer do the whole job.

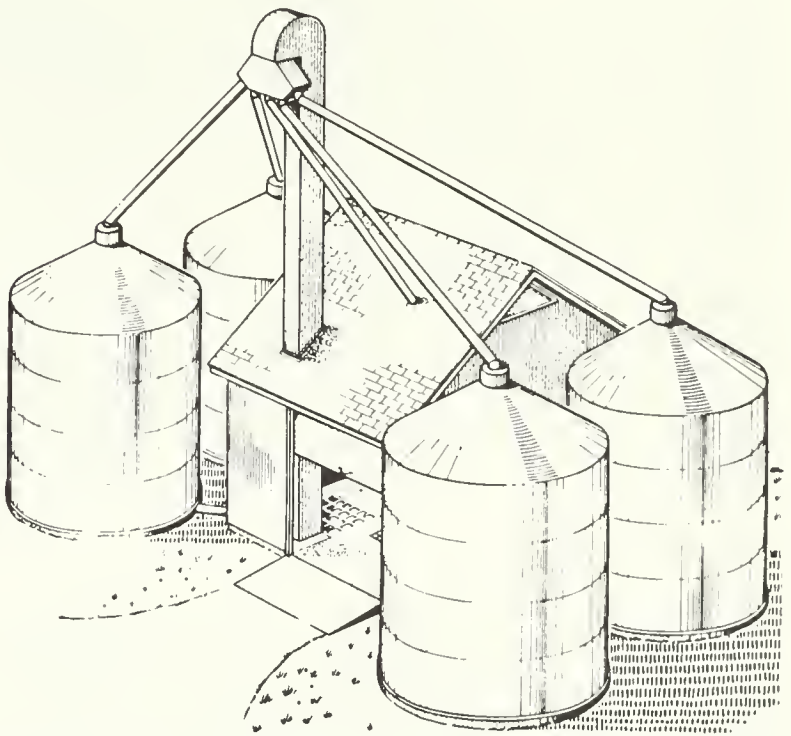


Figure 6.2.3 A well-planned grain handling and storage system with circular storage bins located around a covered grain handling and processing center. A grain drying system can be added between a pair of storage bins if desired.

TABLE 6.2.1 Static Pressure and Energy Requirements for Grain Aeration Fans (34)

Material	Depth of grain (m)	Static pressure (kPa) when air flow is:		Energy when air flow is:	
		1.2L/(s·m ³)	0.5 L/(s·m ³)	1.2 L/(s·m ³)	0.5 L/(s·m ³)
Corn and soybeans	Up to 6	0.174	0.124	0.66	0.16
	6 to 9	0.224	0.149	0.79	0.18
	9 to 12	0.323	0.174	1.19	0.21
	12 to 15	0.472	0.199	1.72	0.24
Wheat and oats	Up to 6	0.398	0.274	1.45	0.32
	6 to 9	0.646	0.348	2.38	0.40
	9 to 12	0.995	0.472	3.56	0.53
	12 to 15	1.492	0.622	5.28	0.79

TABLE 6.2.2 Equilibrium Moisture Content of Grain (%), When Held in Air at 25°C

Grain	Air relative humidity, (%)					
	90	75	60	45	30	15
Barley	19.5	14.5	12.0	10.0	8.5	6.0
Shelled corn	19.0	14.5	13.0	10.5	8.5	6.5
Oats	18.5	13.5	11.5	9.5	8.0	5.5
Grain sorghums	18.5	15.0	12.0	10.0	8.5	6.5
Soybeans	18.5	13.0	9.5	7.5	6.5	5.0
Wheat	20.0	14.5	12.5	10.5	8.5	6.5
Flaxseed	15.0	11.0	8.0	6.5	5.5	4.5

With large-scale operations a more permanent installation is essential for efficient organized material flow. The progressive farmer today should be planning 5-10 years in advance when he will be handling at least double his present production.

Large-scale layouts usually begin with a central structure and overhead surge bins for seed cleaning or feed preparation, and to provide an enclosure for the drive-through, grade dump and vertical elevator. Processing equipment may also be accommodated in the work center. Clusters of storage bins and grain drying facilities are located to provide closed handling loops around the vertical elevator.

It is good practice to provide several different bin sizes rather than one or two large units. The higher initial cost is easily offset by the more flexible management opportunities. Volumes of different crops vary from year to year. Also, separate storage may be needed, for instance, for moldy grain at harvest, or for feed grain purchased at a good price.

6.2.2.2 Cylindrical Grain Bins

The upright cylinder is the most popular and economical shape for granular-material storage, for two reasons: lateral pressures are held by circumferential tension in the wall skin with negligible bending moments; and a given area of flat wall material made into a cylinder encloses the maximum volume. However, the geodesic dome, gothic dome and one storey gambrel roof also provide low-cost storage for granular materials, especially when the angle of repose of the stored material approaches the contour of the roof slope.

Cylindrical bins are constructed from galvanized or a sheet steel, steel-reinforced concrete, plywood and other panelling materials, as these materials adapt readily to a convenient radius of curvature.

Foundations for Cylindrical Grain Bins

Temporary foundations for steel grain bins have been made from a circle of loose concrete blocks bound with wire, and the resulting enclosure filled level with gravel. This type of foundation applies only to steel bins with a built-in steel bottom; it is almost as expensive as a good concrete slab base and should therefore be used only when the bin is to be moved later.

Nineteen floor types were tested for grain storage, by E.R. Gross (18). His summary, in part, reads as follows:

“Three general types of floors are effective as follows:

1. Floors supported on joists with free air circulation beneath, flooring materials used being single boards, double boards with paper between and sheet steel; 2. sheet steel on a fill of earth or gravel; and 3. concrete with an effective moisture barrier.

Three general types failed: 1. Concrete without moisture barrier, on earth or gravel fill, 2. concrete with a board overlay, and 3. concrete surfaced with either one or two coats of emulsified asphalt.”

Stahl (35) similarly tested various floor combinations. He found that the joint between the wall and the floor was frequently the point of entry for water into the bin. Caulking was not always effective in sealing the joint, especially where the bin walls were placed on a wood or concrete platform larger than the base of the bin. He recommended that concrete slab foundations be

constructed slightly smaller than the perimeter of the bin. This makes it possible to extend the bin wall skin below the top of the concrete to provide a drip. For bins previously installed on oversized platforms, Stahl recommended a steel drip flashing to be fastened and caulked to the bin wall and extended down and out over the foundation platform.

Polyethylene film is now used extensively as a vapor and moisture barrier in preference to rolled roofing, because of its low cost and ease of application. Figures 6.2.4 and 6.2.5 illustrate construction of a good foundation for use with an all-weather cylindrical grain bin.

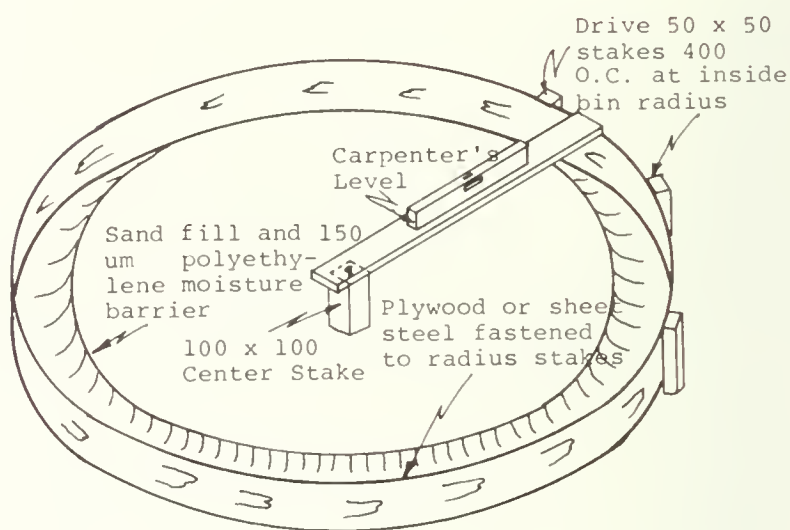


Figure 6.2.4 Dry concrete floor for circular grain bins.

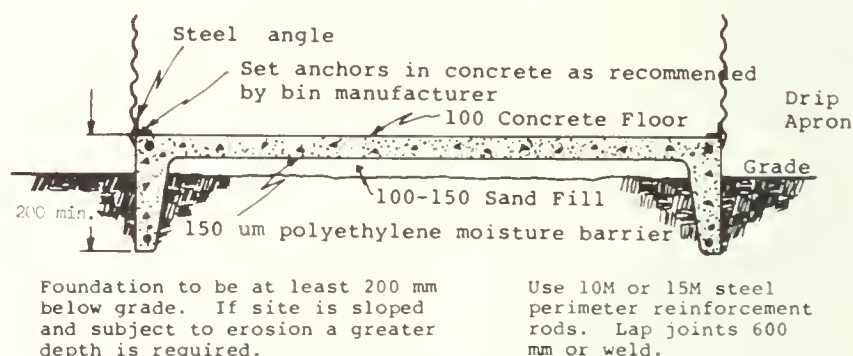


Figure 6.2.5 Section showing details of concrete floor for circular grain bins. Refer to Canada Plan Service Plan No. 7213 for construction details. Above recommendations are for grain bins up to 6 m diameter. Bins greater than 6 m diameter will require a wider footing under the foundation.

Cylindrical Galvanized Steel Bins

The prefabricated steel bin is the most economical and generally the most suitable structure for farm grain storage. Figure 6.2.7 illustrates a typical prefabricated steel bin for grain storage, showing the roof ladder, adjacent manhole roof panel for access to the bin and ventilator, and two-tier access door for grain removal. Such bins are available in capacities from 400 m³ to 16 000 m³.

A storage bin of this type can be easily converted to a drying bin by constructing a false floor in the bottom to provide an air plenum for the distribution of drying air. The

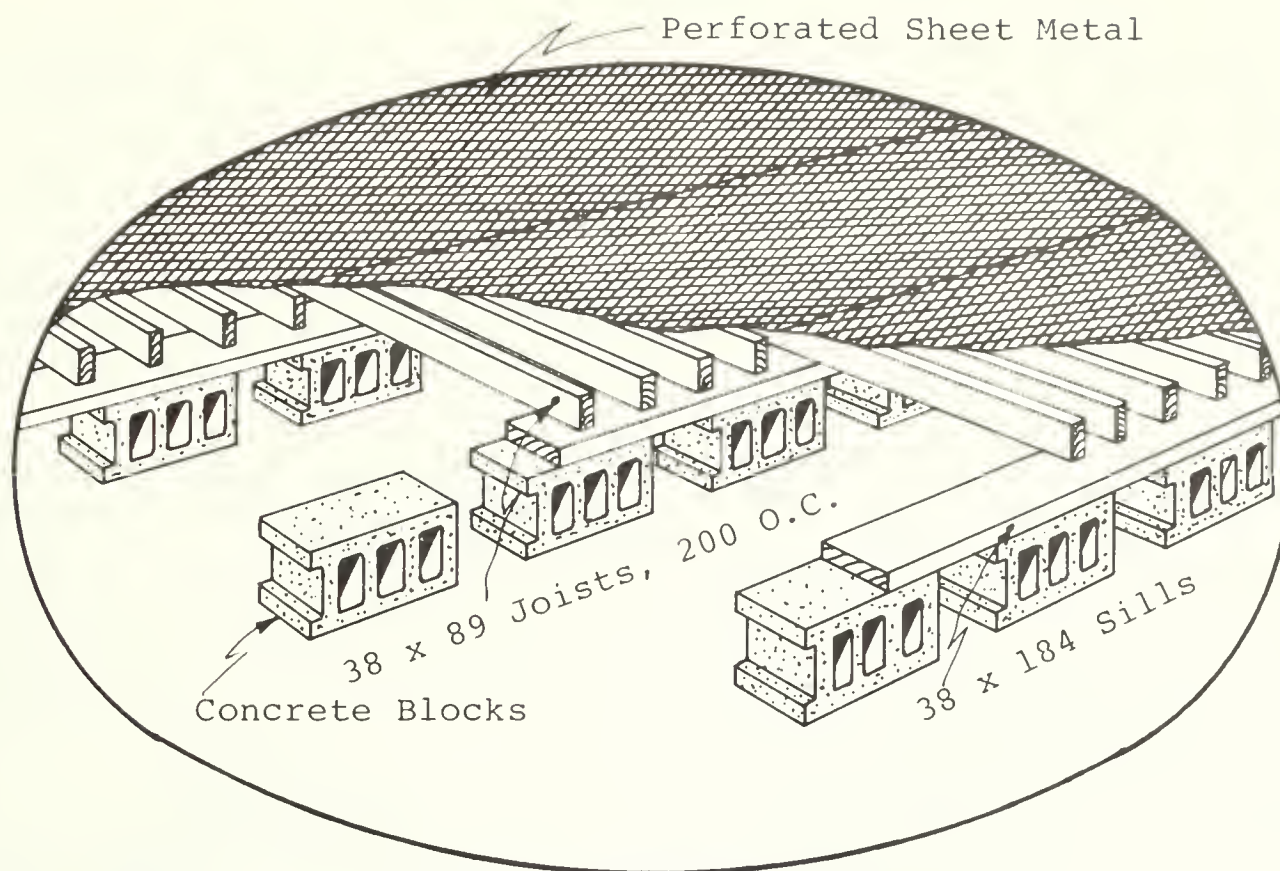


Figure 6.2.6 A false floor can provide air distribution in an existing grain bin.



Figure 6.2.7 A typical prefabricated galvanized steel bin for grain storage showing roof ladder, roof manhole and two-tier access door for grain removal.

details for such a floor system are illustrated in Figure 6.2.6. A concrete floor is not necessary in these situations.

Circular Bin Arrangement for Grain Storage

Circular bin arrangements are discussed by Harder (21) as a means to centralize and improve the efficiency of grain handling systems. By arranging the storage bins in a circle

around a central pit, grain can be dumped into the pit and elevated into the storage bins with a portable inclined auger. The auger pivots at the center of the pit and with the wheels turned perpendicular to the frame, the auger can be moved from bin to bin. A short unloading auger can return the grain from the storage bins to the center pit for truck loading or to transfer grain to another bin in a drying program.

1. Location: The complete facility should be located in a well-drained area, especially if hopper-bottom bins or pits are to be placed below ground level. Avoid areas with a high water table.

The location should have access to an all-weather road. Adequate shelterbelts should be planned around the bins to reduce snow drifting and accumulation in the centre of the circle.

When grain is used for livestock production, the grain center should be located near the feeding area. The structure for feed processing would be substituted for a bin in the circle. Processed feed would be augered or conveyed directly to the animals.

A grain drying system can be included by using a bin in the circle and converting it into a drying bin. The drying bin

can be filled directly from the truck, using a farm auger, or from a hopper-bottom holding bin beside the dryer. After drying, the grain can be unloaded into the center pit for distribution to another bin for storage.

2. Storage Capacity: The size and number of bins in a circular arrangement should hold the capacity required for the farm. Expansion can be provided by starting with several bins placed in a semicircle and adding additional bins as increased storage is required. Be careful to select bins of sufficient capacity to provide adequate storage when the circle is complete.

An additional bin handling system can be added to the basic design, by swinging new bins off the first circle in an S arrangement, as shown in Figure 6.2.9. The new circle also has a pit at its center.

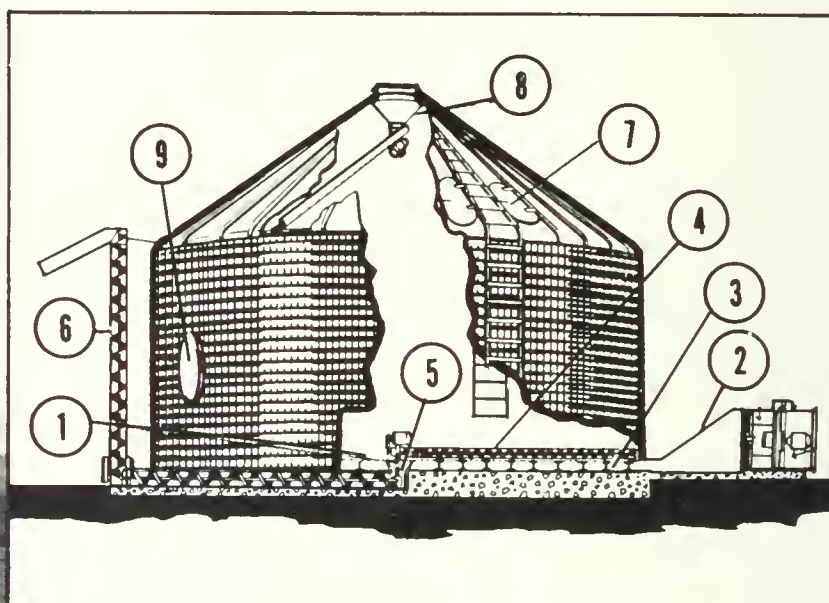
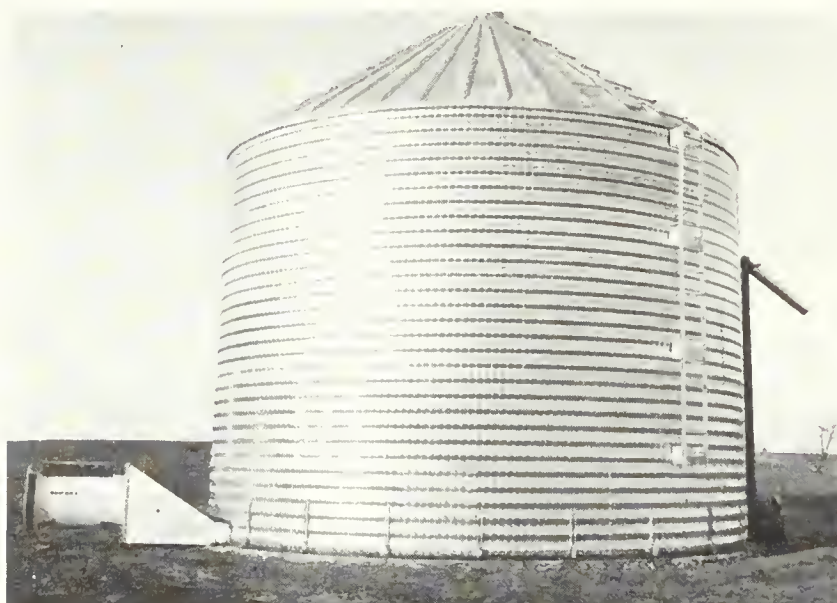


Figure 6.2.8 A prefabricated steel bin complete with most of the accessories available including an air plenum and a built-in supplemental heat unit for in-storage drying in grain. 1. Perforated floor (completely unobstructed); 2. Fan-to-plenum chamber adapter; 3. 300 mm high bar mesh floor supports; 4. Powered sweep auger for unloading tank; 5. Center unloading port; 6. Vertical unloading auger; 7. Two roof access doors; 8. Powered grain leveler (motor included); and 9. Walk-in grain door.

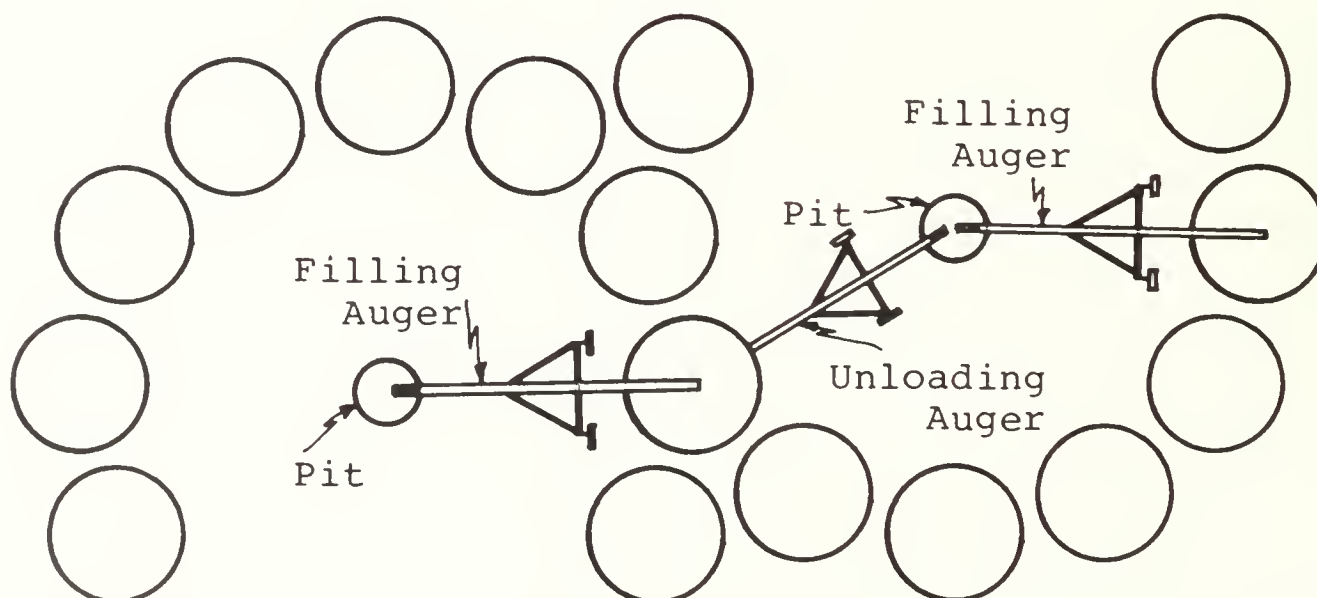


Figure 6.2.9 Circular bin arrangement expanded into an S.

Cylindrical Plywood Bins

Cylindrical plywood grain storage bins have been used extensively in Western Canada and to a lesser extent in Eastern Canada. The circumferential stresses caused by pressure in the stored grain are resisted only by those veneers with the longitudinal grain parallel to the hoop stress. By orientating the face grain of the plywood horizontally, then two plies of three-ply material will be in the effective tension. Vertical joints between the ends of butted plywood sheets are nail-glued between 100 mm wide strips of plywood.

The plywood wall skin is nailed to a stud frame which supports the roof weight and the weight of grain transferred to the walls by friction. Refer to Canada Plan Service, Plan No. 7203 for construction details of "Circular Granaries - 2200, 3300 and 4400 Bushels". All of these granaries are 6.21 m diameter. The 2200 bushel capacity granary is 2.44 m high; the 3300 bushel granary is 3.66 m high; and the 4400 bushel one is 4.88 m high to the top of the plate.

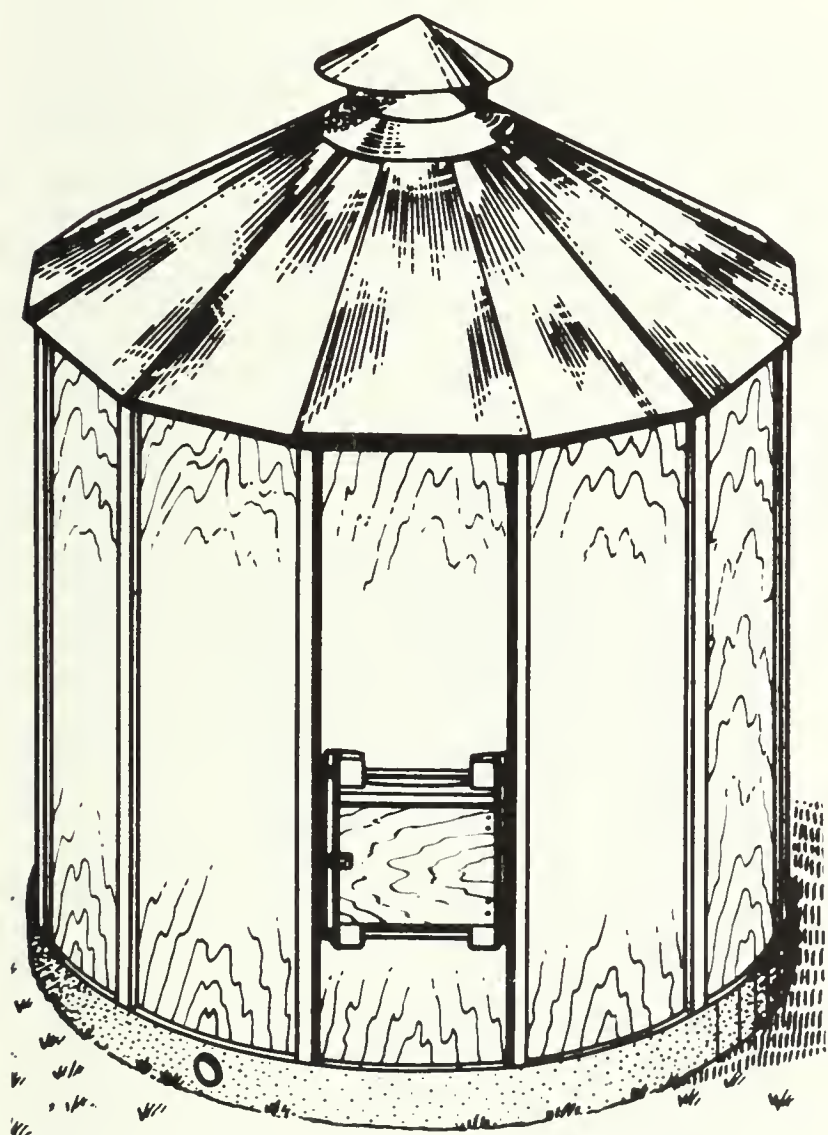


Figure 6.2.10 Low-cost circular plywood grain bin

Figure 6.2.11 shows a small low-cost cylindrical plywood grain bin using 1200 x 2400 mm sheets of plywood in a vertical position. This type of bin can also be used without a roof by incorporating it in new or existing structures for protection from the weather.

The bin is constructed by nailing plywood sheets along the long dimension. When the required number of sheets have been assembled, the joined panel is elevated to the

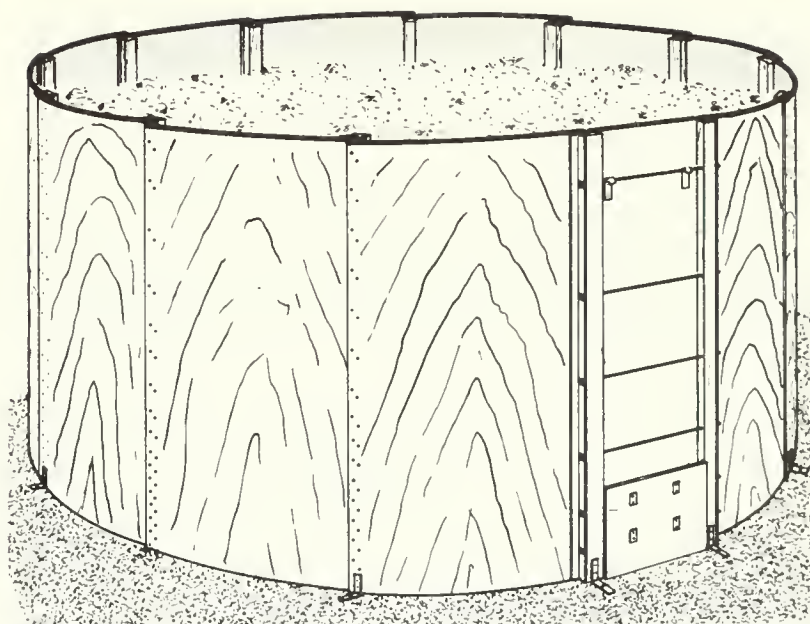


Figure 6.2.11 Circular plywood bin for grain or granular fertilizer storage (from Canada Plan Service Plan 8421).

vertical position and the two ends are brought together and joined to form a cylinder.

The lumber verticals at each joint serve two purposes; they provide nailing depth for the nails, and they provide vertical stiffening for the bin. The verticals can also be fastened to an adjacent building frame or nearby bins for additional support wherever possible.

The construction offers flexibility in that the plywood can be sawn out later and reused for other purposes. Bins can be made collapsible by bolting the final joint instead of nailing.

Joint Design for Cylindrical Plywood Grain Bins

Example Problem: To find the lateral pressure and the circumferential (or band) tension in the bottom metre of a cylindrical plywood grain bin; to design the plywood wall and the lap joint required.

Given the following:

- Bin diameter, $D = 5$ m
- Bin wall height, $h = 2.4$ m
- Stored material is wheat, with the following physical properties (5):
 - Bulk density, $w = 800 \text{ kg/m}^3 = 7.85 \text{ kN/m}^3$
 - Ratio, lateral pressure to vertical pressure, $k = 0.6$
 - Coefficient of friction, wheat on smooth wood, $u' = 0.361$

The following formula, from Janssen (5) is applicable to design of deep storage for granular materials, and is probably over-safe for storages proportioned as above:

$$L = \frac{w R}{u'} \left(1 - e^{-\frac{k u' h}{R}} \right) \dots \dots \dots (1)$$

- Where w , k , u' and h are as defined above, and
- L = horizontal component of grain force in wall, kN/m^2
- R = hydraulic radius of bin = A/C
- A = floor area of bin
- C = circumference of bin
- e = natural logarithm base = 2.71828

Lateral pressure can be determined from equation (1) above, and used to compute band tension from the following:

$$T = \frac{LD}{2} \dots\dots\dots (2)$$

Where T = band tension, kN per vertical m of wall
L and D are as defined above.

Substituting values appropriate to the first metre of bin wall into equation (1) we have:

$$R = \frac{D^2}{4 D} = \frac{D}{4} = \frac{5}{4} = 1.25$$

$$L = \left(\frac{7.8 (1.25)}{0.361} 1 - e^{\frac{-(0.6) (0.361) (2.4)}{1.25}} \right) 9.19 \text{ kN/m}^2$$

From equation (2) we now have

$$T = \frac{(9.19) (5)}{2} = 22.98 \text{ kN/m}$$

The Code for Engineering Design in Wood (37) gives the following criteria applicable to this problem: with 9.5 mm unsanded sheathing fir plywood, center veneer thickness is 3.0 mm; allowable tensile stress (f) perpendicular to face grain is 8.20 MPa. For low human occupancy farm buildings, working stresses can be increased 25%, thus 8.20 (1.25) = 10.25 MPa allowable.

Tensile stress in the core veneer is checked as follows:

$$f = \frac{22.98 (1000)}{3.00 (1000)} = 7.66 \text{ MPa}, < 10.25 \text{ MPa, therefore safe}$$

The nailing detail for the lapped plywood joints consists of two or three rows of large-head galvanized roofing nails, driven through the lapped plywood and into a 38 x 89 stud laid flat. Based on Turnbull (40), allow 0.55 kN transverse load per nail when nailing through two layers of 9.5 mm fir ply.

Nails required at the bottom of the wall joints are:

$$\frac{22.98 \text{ kN/m}}{0.55 \text{ kN/nail}} = 42 \text{ nails/m}$$

Therefore, use two rows of nails spaced 48 mm apart each row. Nail spacing can be gradually increased towards the top of the wall.

Table 6.2.3 lists a range of bins using this method of construction, adapted from Canada Plan Service Plans

8421 and 8422. Larger and taller bins can be built with the plywood face grain placed horizontally instead of vertically; this eliminates the limitation of the low working stress allowed for plywood core veneers which are now frequently made from weaker softwood species such as spruce.

Cylindrical grain bins made with plywood and enclosed within weather and rot-proof single-storey sheds can compete with manufactured steel grain bins, especially where the storage capacity of each bin is relatively small. Figure 6.2.12 shows a plan for a farm-sized grain-handling plant using this principle.

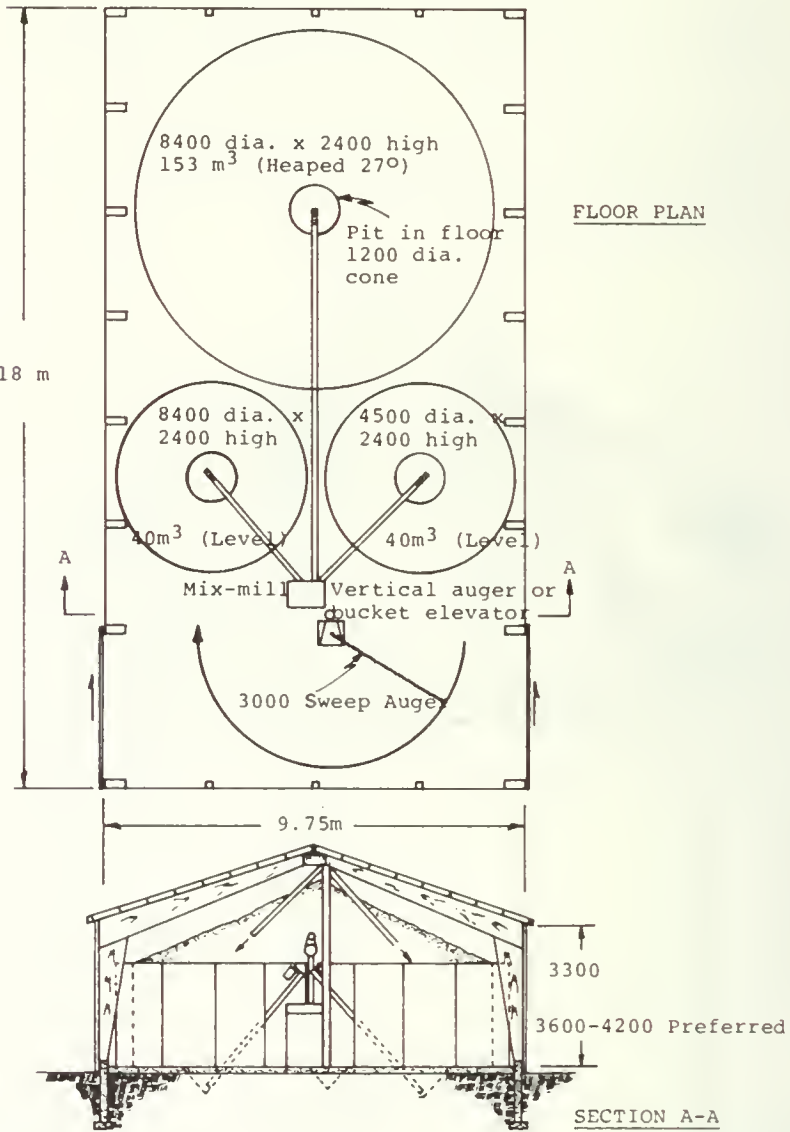


Figure 6.2.12 Farm-sized grain-handling plant using cylindrical plywood grain bins.

TABLE 6.2.3 Dimension of Cylindrical Plywood Bins

Factors	Bin wall height = 2400 mm		
Bin diameter, mm	3052	4467	5881
No. of plywood sheets	8	12	16
Size plywood sheets, mm	7.5x1200x2400	9.5x1200x2400	9.5x1200x2400
Bin capacity level full, m³	17.56	37.28	65.19
Bin capacity heaped 28°, m³	19.54	43.48	---
Bin wall height = 1200 mm			
Bin diameter, mm	3165	4637	6108
No. of plywood sheets	4	6	8
Size plywood sheets, mm	7.5x2400x1200	7.5x2400x1200	7.5x2400x1200
Bin capacity level full, m³	9.44	20.26	35.16
Bin capacity heaped 28°, m³	11.65	27.2	51.02

The use of low-cost plywood bins enclosed in a single-story enclosure offers some advantages over a number of small steel bins having the same total storage capacity, namely:

1. One simple building contains all the grain and related handling and processing equipment.
2. While the cost of the actual storage space, including the cost of the plywood bins, may be slightly more than the equivalent storage capacity of steel bins, the cost of the grain handling and processing space will be less since one wall is eliminated.
3. The building can easily be rearranged for other uses.

Cylindrical Fiberglass Bins Fiberglass reinforced plastics have been used as structural materials for more than 25 years. Flanged plates were bolted together to form a tower silo for silage storage as early as 1951. More recently, cable-reinforced plastic panels have been assembled in diameters as large as 30 m for liquid storage in the chemical industry. Special resin formulations can be prepared to provide resistance to a wide variety of corrosive chemicals.

This feature is now being applied to grain storages and is especially useful for storage of acid-treated grain. Such a cable-wrapped, fiberglass reinforced grain bin is illustrated in Figure 6.2.13. At present they cannot compete economically with cylindrical steel bins for normal grain storage, but as the demand increases and more companies get into the business, they may become competitive.



Figure 6.2.13 A cable-wrapped, fiberglass-reinforced grain bin. Arkell Research Station, Ontario Ministry of Agriculture and Food, Guelph, Ontario.

6.2.2.3 Rectangular Wood Bins

Since wood is a convenient material to work with, rectangular wood bins are in common use on many farms. The following points should be considered:

1. Rectangular wood bins are generally more expensive to build than the equivalent cylindrical storage.
2. Rectangular construction is more familiar to builders.
3. Roofs and sloping bottoms are simpler to build in rectangular bins.

Rectangular storages can compete economically with cylindrical storages in units of 350 m³ and larger, providing the length to width ratio does not exceed 2:1.

Rectangular Plywood Grain Bins

These are generally constructed of vertical studs using dimension lumber, lined with plywood and reinforced around the perimeter with horizontal components connected from opposite sides by steel rods, as illustrated in Figure 6.2.14 (A).

Rectangular Grain Bins, Cribbed Construction

Cribbed construction is made by nail-laminating dimension lumber, with the corners alternately lapped to connect adjacent walls as illustrated in Figure 6.2.14 (B).

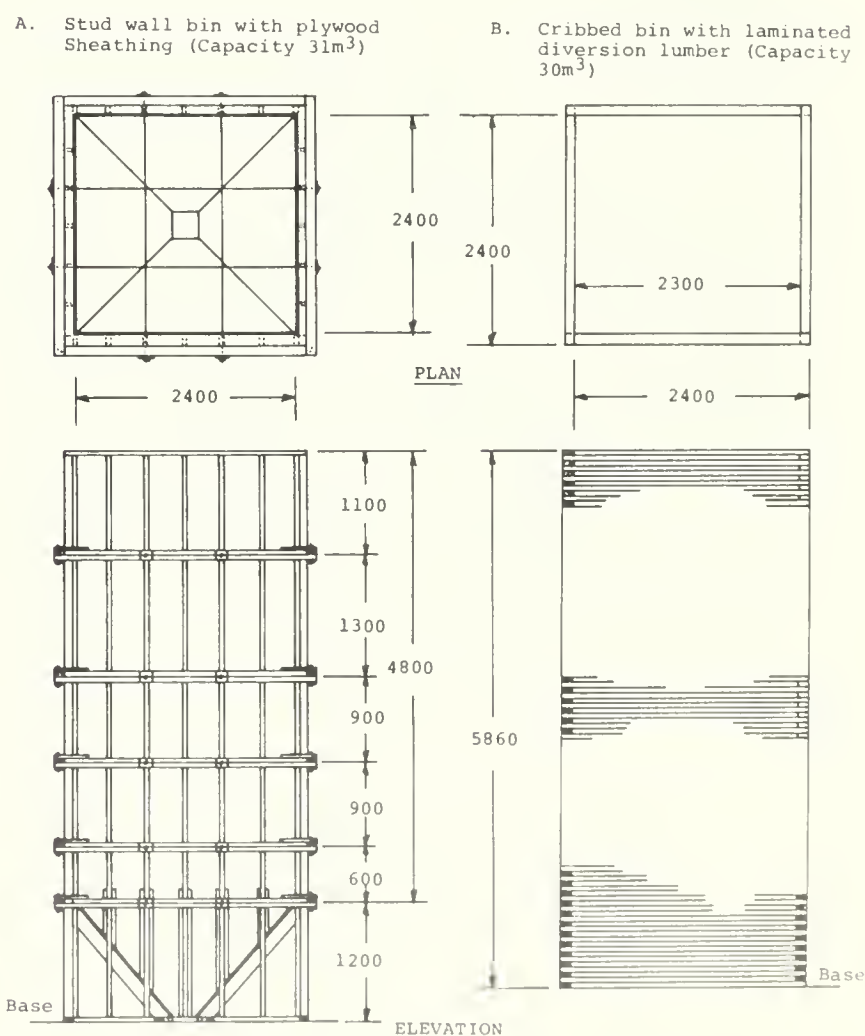


Figure 6.2.14 Comparison of stud-wall grain bin with cribbed laminated dimension lumber construction.

Cribbed construction is convenient where several bins share common walls. This type of construction is not recommended for bins with hopper bottoms since a large part of the vertical wall material around the hopper bottom portion serves only to support the vertical weight.

The plywood bin is much less expensive to build — about 60% that of the cribbed bin. For construction plans for both types of grain storages, see Canada Farm Building Plan Service Plan Nos. 7200, 7201 and 7207.

6.2.2.4 Rectangular Horizontal Grain Storage

Rectangular, horizontal grain storage is economical in large units (400 m³ and larger) with the added advantage that it is easily adaptable to other uses, such as machinery storage, bulk feed storage and livestock housing. Horizontal storage is limited in practice to specialized crop production where the storage is for one crop only, and it is not necessary to subdivide the space for different crops. For convenience in loading and unloading, the interior should be post free.

Adequate walls can be designed to resist grain pressures without extra support if the height of grain is kept low at the wall. This is illustrated in Figure 6.2.15 where the space within the trusses is used to advantage. In this case, as well as where horizontal girts or vertical studs are secured to rigid frames or plates and foundation floor systems, special consideration must be given to the design of structural connections. "Universal joist hangers" or special metal fasteners as used in residential and industrial building construction may be used for this purpose. See Figure 6.2.16 for an example of this type of connector.

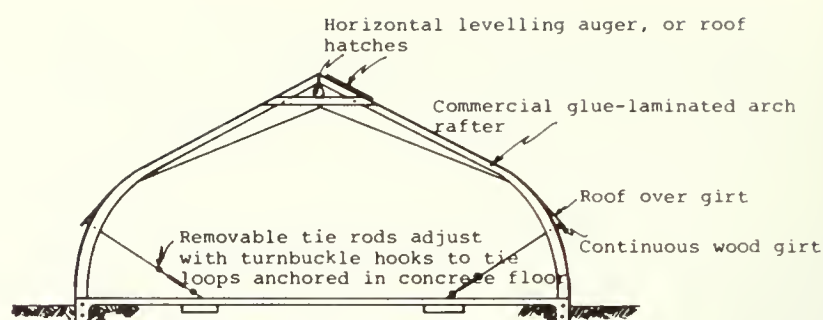


Figure 6.2.17 Section of rectangular horizontal grain storage building with one-hinged laminated arch roof.

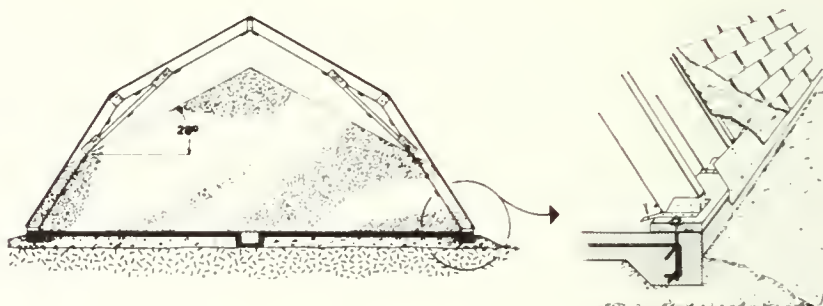


Figure 6.2.18 Gambrel roof arch frame adopted for grain storage (from Canada Plan Service Series M-9250).

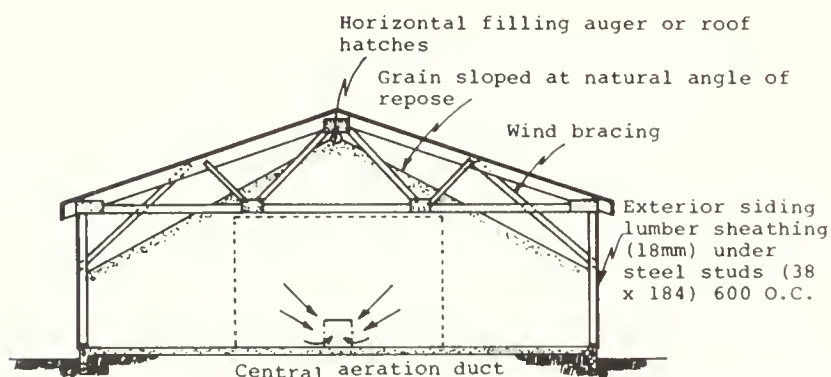


Figure 6.2.15 Section of rectangular horizontal grain storage building with W-truss. Roof trusses must be designed for normal roof loads and lateral thrust of walls.

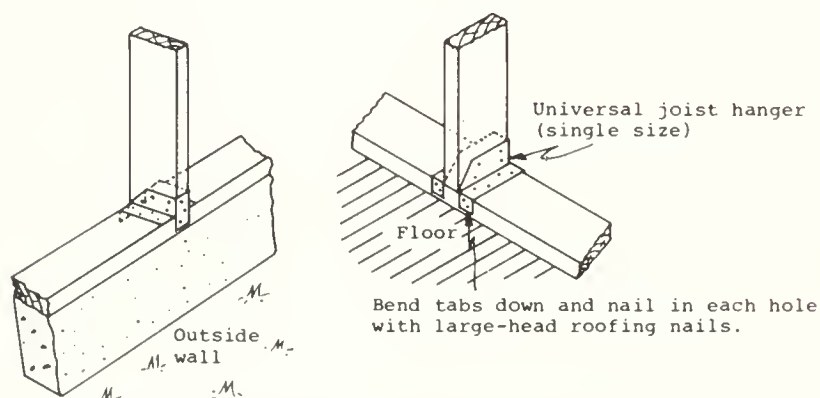


Figure 6.2.16 Typical detail of stud connection to floor or foundation sill for grain storage walls.

Where grain is to be stored at depths greater than 2 m at the outside walls, or where a building was not originally designed for grain pressure, steel tie rods can be attached from wall to floor. See Figure 6.2.17 for illustration of a laminated-arch structure converted to grain storage. It

should be noted that a considerable reduction of wall pressure can be accomplished by sloping walls in toward the grain at the top.

Figure 6.2.18 shows the traditional gambrel roof arch adapted for grain storage. Gambrel roofs having rafter slopes as illustrated can be easily designed to eliminate the need for the additional tie rods shown in Figure 6.2.17. Calculations show that grain pressures increase the rafter bending moments about 20% above the moments due to snow loading. With grain stored in contact with sloping rafters there will also be an increase in the uplift forces (wind + grain) which must be considered in design of the rafter-to-foundation connections. For this, use extra strap-ties or steel flashing nailed from rafters to sill, and extra anchor bolts from sill to foundation.

6.2.2.5 Vertical Silos for Grain Storage

Conventional vertical silos can be used successfully for large grain storage units, with minor alteration. A very important advantage of the silo, built as a dry grain storage, is that it can be used for storage of forage crops and high-moisture grain without additional circumferential reinforcement. On the other hand, silos originally designed for crop storage can easily be modified to permit the storage of grains.

Loads Imposed by Stored Grain

In general, most design information is related to shallow bin storage or deep bin storage. The Canadian Farm Building Code, 1977, defines a shallow bin as "depth of grain (H) less than or equal to equivalent diameter (D)" and a deep bin as "depth of grain (H) greater than the equivalent diameter (D)". For circular bins, the equivalent diameter is the bin diameter. For rectangular bins, the equivalent diameter is given as:

$$D = \frac{4 (\text{floor area})}{(\text{perimeter})}$$

Shallow Bins

Grain is considered a semifluid, therefore both vertical and lateral loads are a function of depth. By using an equivalent fluid density (EFD) which directly relates load and depth, assuming linearity, the calculations for lateral and vertical loads are somewhat simplified. EFD values for a few typical grains are given in Table 6.2.4.

- (1) Lateral load on vertical walls:

$$1 = (\text{EFD}) H$$

where 1 = lateral load, kN/m³

(EFD) = equivalent fluid density kN/m³,
Table 6.2.4

H = depth of grain, m

- (2) Total lateral load on a vertical wall section:

$$L = (\text{EFD}) \frac{H^2}{2}$$

where L = total lateral load on a vertical wall section, 1 m wide. Other notations are as previously defined

- (3) Vertical load on vertical walls:

$$V_v = u' L$$

where V_v = vertical load, kN/m²

u' = coefficient for friction for grain on wall surface

- (4) Vertical loads on horizontal floors:

$$V_f = (\text{EFD}) H$$

For conservative estimates, use bulk density for (EFD), Table 6.2.5.

Deep Bins

- (1) Lateral load on vertical walls:

Janssen's formula is the most commonly used method for calculating lateral pressures in deep bins.

$$L = \frac{wD}{4u'} \left(1 - e^{-\frac{4Ku'H}{D}} \right)$$

where L = lateral pressure, kN/m²

w = material density, kN/m³

D = bin diameter or equivalent diameter, m

k = ratio of lateral to vertical internal pressure

$$= \left(\frac{1 - \sin \phi}{1 + \sin \phi} \right)$$

ϕ = angle of repose, Table 6.2.4

u' = coefficient of friction, material on wall,
Tables 6.2.6 and 6.2.7

H = depth of grain, m

e = naperian log base

- (2) Vertical load on vertical walls:

$$V_v = u' L$$

Note - vertical load and horizontal load may never be maximum at the same time.

- (3) Vertical load on horizontal floors:

$$V_f = \frac{L}{K}$$

- (4) Lateral pressures for silage not over 70% moisture, (WB), stored in concrete silos, can be determined using following formula:

$$L = 4.785 + 0.579 h d^{0.55}$$

where L = lateral pressure, kN/m²

h = vertical distance from the top of the silo wall, m

d = silo diameter, m

Note - this formula is not intended for design of circular grain storages, but concrete silos designed by use of this formula are reasonably safe for normal pressures from shelled corn in storage.

Lateral pressures for corn silage and dry shelled corn are plotted in Figure 6.2.18. It should be noted that the apparent densities shown in Table 6.2.5 for silage stored at an average depth of 24 m is approximately 14% greater than the actual obtained by Jackson and Lessard from their studies (23) of a 9 m diameter by 24 m poured-concrete silo filled with corn silage at average dry matter contents of 28.3, 32.9 and 45.4 in 1971, 1972 and 1973, respectively. Therefore, the lateral pressure curves shown in Figure 6.2.19 are conservative.

It should be emphasized that the use of Janssen's equation, for lateral grain pressures shown in Figure 6.2.19, is applicable only to grain at safe storage moisture content. Dale and Robinson (13) found that dried corn, dampened in storage, (by ventilation with moist air) expanded enough to remove all grain weight from the walls. The weight of the corn was transferred entirely to the floor. Dampening the dry corn within the container increased the lateral pressure 10 times. For this reason, any situation which permits an increase of stored grain moisture should be avoided, for example, leaking roofs or mechanical aeration during long periods of high humidity.

TABLE 6.2.4 Angles of Repose and Equivalent Fluid Densities for Some Grains*

Grain	Angle of repose deg	Equivalent fluid density kg/m ³	Equivalent fluid density kN/m ³
Barley	28	230-250	2.25-2.45
Corn, shelled	27	288	2.82
Flaxseed	25	280	2.75
Oats	32	165-173	1.62-1.70
Rye	26	290	2.84
Soybeans	29	258	2.53
Wheat			
-Hard red winter	27	293	2.87
-Soft red winter	27	308	3.02
-Hard red spring	28	301	2.95

*Adapted from Canadian Farm Building Code, 1977

TABLE 6.2.5 Apparent Densities of Agricultural Materials*

Material	Apparent density, w	
	kg/m ³	kN/m ³
Grains		
Barley	640	6.28
Flaxseed	720	7.06
Oats	400-560	3.92-5.49
-ground or rolled	300-400	2.94-3.92
Rapeseed		
-Polish	640	6.28
-Argentine	770	7.55
Rice	577	5.66
Rye	720	7.06
Soybeans	770	7.55
Wheat	770	7.55
-ground	609	5.97
Corn		
-shelled 15% moisture	720	7.06
-shelled 25% moisture	738	7.24
-ground shelled	817	8.01
-husked ear	448	4.39
-ground ear	577	5.66
Roughages		
Hay		
-long	64-80	0.63-0.78
-chopped	128-160	1.26-1.60
-baled, twine	96-128	0.94-1.26
-baled, wire	160-225	1.57-2.21
-wafered	320	3.14
Silage		
-stored depth av (3 m)	565	5.54
-stored depth av (9 m)	657	6.44
- stored depth av (12 m)	745	7.31
-stored depth av (15 m)	814	7.98
- stored depth av (18 m)	881	8.64
-stored depth av (21 m)	948	9.30
-stored depth av (24 m)	1017	9.97
Straw		
-long	56-64	0.55-0.63
-chopped	96-128	0.94-1.25
-loose baled	112-128	1.10-1.25
-wood shavings baled	320	3.14

*Adapted from ref. (36).

Walls for cylindrical storages should be designed for the dead load of the walls and roof plus the live loads due to loading equipment supported by the walls and the vertical wall friction of the silage. For top-unloading concrete silos, vertical wall friction may be approximated by assuming that the wall at its base supports the weight of the silage above a right circular cone with base the floor of the silo and height of 4.7 times the silo diameter. Use apparent density of silage in Table 6.2.5.

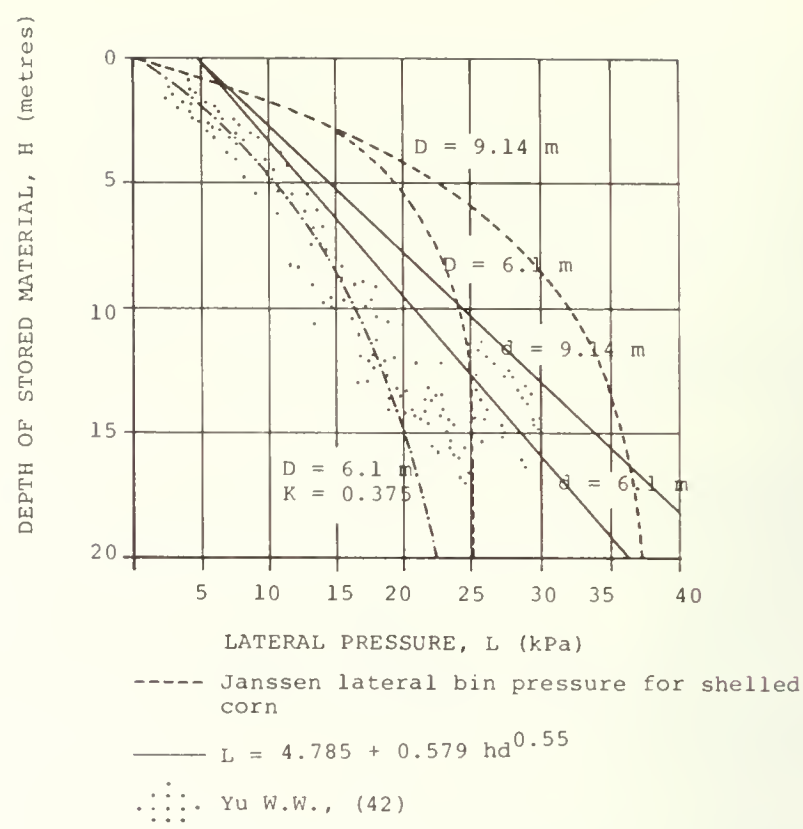


Figure 6.2.19 Lateral pressures for corn silage and dry shelled corn

6.2.2.6 High-moisture Grain Storage

High moisture grain, hermetically sealed in a storage structure, goes through stages of biologic alteration involving the suffocation of the seed germ and the development of yeasts and moulds. These processes use up the limited oxygen supply until further fermentation is halted. Re-exposure to natural air permits rapid development of these yeasts and moulds in the fermented grain.

Grain, stored as high-moisture material, is therefore suitable only for livestock feed, at or near the point of storage.

High-moisture Grain Storage in Concrete Silos

Grain, particularly corn, can be successfully stored in sound, crack-free concrete silos (both stave and poured types); silos for this purpose should be roofed. The following special precautions have been found necessary to preserve the moist grain for feeding purposes:

1. Store grain between 23-35% kernel moisture content, wet basis. Moisture contents from 25-30% are preferred.
2. Do not add water if moisture falls below 23% during harvest, because of destructively high storage pressures (13).
3. Store corn as shelled whole or cracked kernels, or as ground ear corn (including cobs). In all cases, spread the material in uniform horizontal layers, to prevent the separation of the larger particles. Increased porosity in the material, particularly near the walls, promotes spoilage.

TABLE 6.2.6 Coefficients of Friction (μ') for Grains at Various Moisture Contents on Concrete and Metal Surfaces*

Material	Moisture content percent (WB)	Concrete			Metal	
		Plastic smooth finish	Steel trowel finish	Wood float finish	Mild steel, cold rolled	Galvanized sheet metal
Oats	10.6	0.28	0.40	0.43	0.20	0.22
	13.0	0.34	0.44	0.44	0.26	0.24
	14.0	0.33	0.51	0.42	0.21	0.18
	16.0	0.29	0.46	0.46	0.20	0.41
	17.3	0.50	0.65	0.64	0.44	0.32
Wheat	11.2	0.36	0.52	0.51	0.20	0.10
	13.0	0.47	0.52	0.55	0.29	0.14
	15.0	0.50	0.55	0.51	0.27	0.27
	15.7	0.56	0.68	0.69	0.51	0.33
Soybeans	7.1	0.25	0.39	0.39	0.19	0.21
	8.1	0.32	0.55	0.52	0.19	0.21
	9.8	0.31	0.47	0.37	0.20	0.18
	12.2	0.36	0.55	0.52	0.23	0.20
Barley	10.7	0.23	0.56	0.50	0.20	0.20
	12.3	0.25	0.55	0.52	0.25	0.17
	14.3	0.24	0.57	0.51	0.29	0.20
	16.4	0.33	0.62	0.55	0.21	0.34
Shelled corn	7.5	0.27	0.41	0.46	0.23	0.20
	9.9	0.25	0.59	0.62	0.20	0.24
	12.2	0.33	0.68	0.65	0.20	0.25
	13.9	0.35	0.64	0.54	0.24	0.37
Alfalfa	82.0	0.74	0.69	0.78	0.65	0.54
	33.3	0.48	0.56	0.71	0.51	0.37
	22.2	0.33	0.65	0.66	0.46	0.36
Alfalfa 75% Timothy 25%	77.0	0.63	0.68	0.78	0.65	0.64
	26.2	0.28	0.49	0.73	0.36	0.38
	21.3	0.26	0.49	0.62	0.35	0.27
Alfalfa 25% Timothy 75%	81.1	0.62	0.69	0.83	0.57	0.59
	49.3	0.51	0.60	0.82	0.43	0.50
Timothy	79.3	0.58	0.60	0.77	0.57	0.53
	38.1	0.46	0.59	0.78	0.43	0.32
	30.5	0.37	0.48	0.73	0.39	0.48
	16.7	0.27	0.45	0.63	0.32	0.32
Bedding-oat straw -shavings	14.95	0.20	0.36	0.45	0.35	0.30
	9.5	0.35	0.70	0.73	0.57	0.38
Corn silage	78.4	0.46	0.56	0.70	0.57	0.49

*Adapted from ref. (36).

TABLE 6.2.7 Coefficients of Friction (μ') for Grains at Various Moisture Contents on Wood and Plastic Surfaces*

Material	Moisture Content percent (WB)	Oak		Douglas Fir		Polyethylene
		Grain Parallel	Grain Perpendicular	Grain Parallel	Grain Perpendicular	
Oats	10.6	0.20	0.23	0.27	0.29	0.20
	13.0	0.24	0.25	0.29	0.35	0.24
	14.0	0.23	0.25	0.34	0.36	0.28
	16.0	0.31	0.31	0.37	0.37	0.31
	17.3	0.46	0.48	0.48	0.50	0.50
Wheat	11.2	0.24	0.26	0.31	0.35	0.27
	13.0	0.25	0.29	0.35	0.38	0.35
	15.0	0.35	0.37	0.47	0.46	0.39
	15.7	0.41	0.46	0.48	0.50	0.45
Soybeans	7.1	0.24	0.34	0.29	0.31	0.25
	8.1	0.29	0.38	0.32	0.37	0.32
	9.8	0.28	0.31	0.33	0.31	0.29
	12.2	0.28	0.36	0.35	0.44	0.43
Barley	10.7	0.23	0.29	0.27	0.32	0.23
	12.3	0.21	0.28	0.28	0.31	0.28
	14.3	0.21	0.28	0.30	0.32	0.28
	16.4	0.30	0.33	0.34	0.41	0.35
Shelled corn	7.5	0.24	0.25	0.27	0.29	0.22
	9.9	0.28	0.31	0.31	0.31	0.27
	12.2	0.26	0.29	0.33	0.33	0.30
	13.9	0.29	0.36	0.37	0.38	0.38
Alfalfa	82.0	0.61	0.67	0.70	0.61	0.61
	33.3	0.37	0.48	0.39	0.49	0.39
	22.2	0.31	0.33	0.33	0.37	0.32
Alfalfa 75% Timothy 25%	77.0	0.58	0.60	0.60	0.70	0.65
	26.2	0.31	0.39	0.36	0.42	0.33
	21.3	0.31	0.36	0.32	0.39	0.19
Alfalfa 25% Timothy 75%	81.1	0.52	0.64	0.66	0.65	0.62
	49.3	0.44	0.56	0.45	0.59	0.61
	21.6	0.31	0.38	0.37	0.43	0.23
Timothy	79.3	0.52	0.53	0.64	0.60	0.66
	38.1	0.51	0.56	0.53	0.64	0.52
	30.5	0.44	0.38	0.42	0.52	0.38
	16.7	0.35	0.42	0.40	0.44	2.1
Bedding-oat straw -shavings	14.95	0.20	0.26	0.22	0.25	0.22
	9.5	0.46	0.53	0.43	0.51	0.29
Corn silage	9.5	0.58	0.57	0.57	0.58	0.40

*Adapted from ref. (36).

4. Seal the silo doors with a continuous roll of plastic film up the inside of the door openings while filling. If a mechanical top-unloader is to be used, do not use the plastic film. Seal the doors against a soft rubber gasket or a thick continuous layer of putty.

5. Seal the top grain surface with a disc of 150 μ m polyethylene or vinyl film. Cut the film with a radius about 600 mm greater than that of the silo. Fit the seal close to the silo wall and hold it down with dry grain.

6. After the silo is opened, feed daily. Design storage size for a minimum removal of 50 mm per day in winter and 100 mm per day in summer.

7. Mechanical top-unloading is recommended over manual; a more uniform layer can be removed each day, to control surface spoilage.

High-moisture Grain Storage in Steel Bins

In general, high-moisture grain cannot be stored successfully in regular steel bins because of the problems of providing a hermetically sealed environment. However, by treating the grain with propionic/acetic acid as a preservative, it is now possible. The acid manufacturers report that the use of acid preservatives eliminates crop storage waste, costly mechanical drying and hermetically sealed storage structures. However, their use has posed a serious corrosion problem on galvanized grain bins.

Recognizing the economy and efficiency of galvanized steel bin construction, the steel industry supported a research program by Theakston (38) to determine the best interior protective lining for the purpose. The actual field test conditions were as follows:

1. Moisture content from 22-30%.
2. Atmospheric temperature, summer through winter, was from 21°C to -18°C.
3. Interior temperature was 2°C.
4. Acid concentration - a range of concentrations were used depending on the moisture content of the grain at the individual test sites.
5. Both new and rusted bins were used.

A rubber-based paint applied by brush or spray proved to be the most effective. One such paint is "Interchlor Protective Lining" which proved effective in terms of corrosion, abrasion, moisture and acid resistance.

The manufacturer recommends that all surfaces be cleaned thoroughly. For new bins, a solvent should be used to remove all oils, grease and sealing compound. First apply the protective lining primer to all seams, bolts and behind structural joints, then follow with an even coat of the same primer over the complete surface at a rate of 10-11 m²/L. This is followed with two top coats of Interchlor Protective Lining White at a rate of 8-9 m²/L.

Since the solvents in both the primer and top coat are reasonably strong and inflammable, all of the precautionary measures normally associated with good painting practice in confined areas should be observed.

High-moisture Grain Storage in Oxygen-limiting Steel Silos

Several manufacturers have developed steel tanks specifically for sealed storage of high-moisture whole grain. These structures are unloaded from the bottom. A relief valve is required to admit a volume of air to the space above the storage, to replace the grain removed from the bottom. A breather system is sometimes used in combination with the relief valve to maintain the gas within the tank at a pressure essentially equal to the varying atmospheric pressure outside.

Sealed storage is more expensive than the conventional silo but it is easier to manage. Rate of grain consumption is more flexible, and feeding can be temporarily discontinued without feed waste.

Whole corn stored at high moisture content tends to bridge over stationary unloading augers. Where only one fixed auger position is possible some unloading should be done immediately after filling is completed. This grain removal sets up a flow pattern in the grain mass, helping to prevent possible bridging.

Several sealed grain storage systems are illustrated in Figures 6.2.20, 21, 22 and 23.

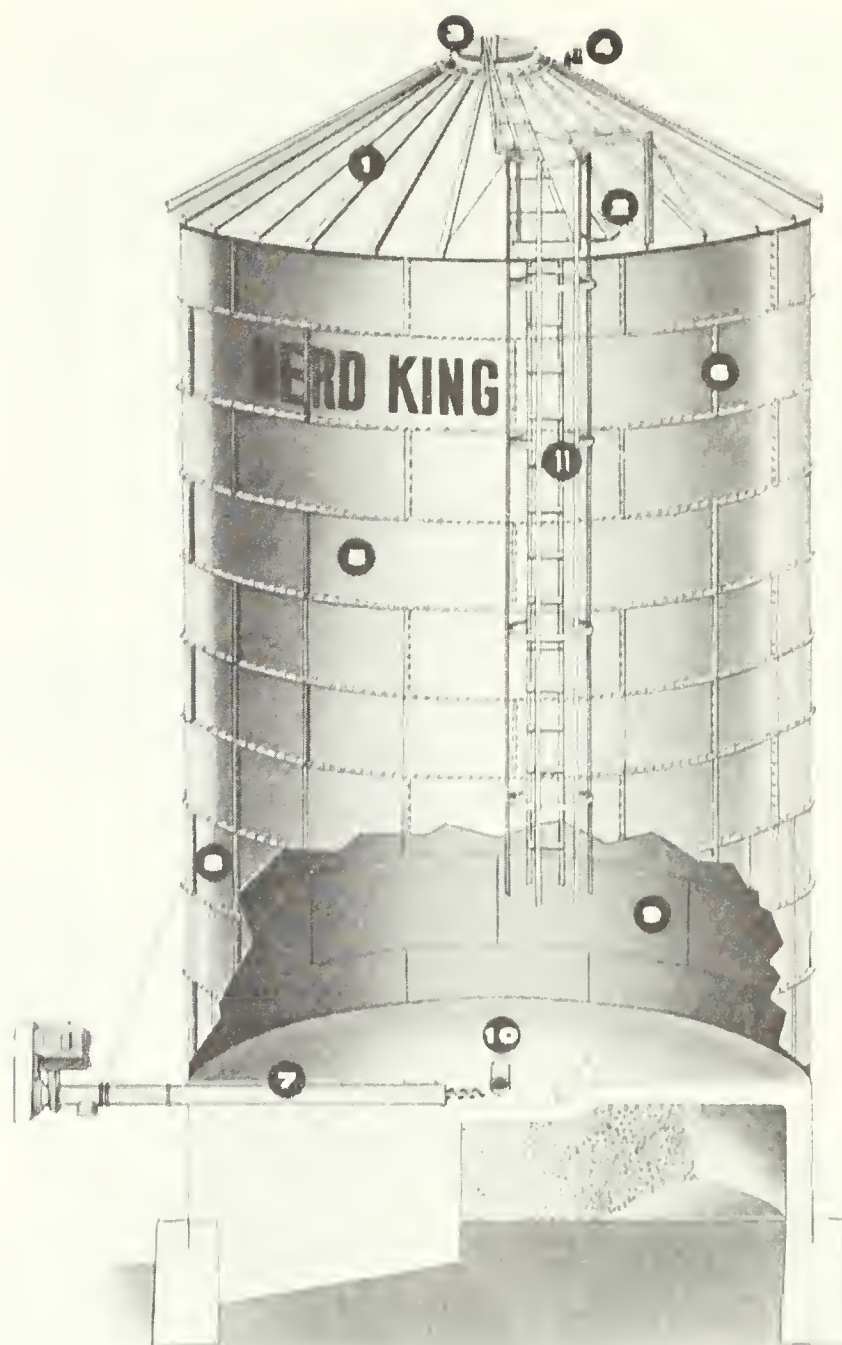


Figure 6.2.20 Oxygen-limiting steel grain storage with standard flat bottom and adjustable-flow unloading auger. Courtesy, Clayton & Lambert Mfg. Co., Farm Products Division, Buckner, Kentucky.

1. Conical roof (stainless surfaced steel)
2. Sealed manhole
3. Sealed unloading door
4. Pressure/vacuum regulator valve
5. Wall panels (stainless surfaced steel)
6. Sealed wide-flange seams
7. "Adjust-a-Flo" unloading auger
8. Steel reinforcement (lower sections)
9. Smooth inside surface
10. Alternative auger tube
11. Safety ladder

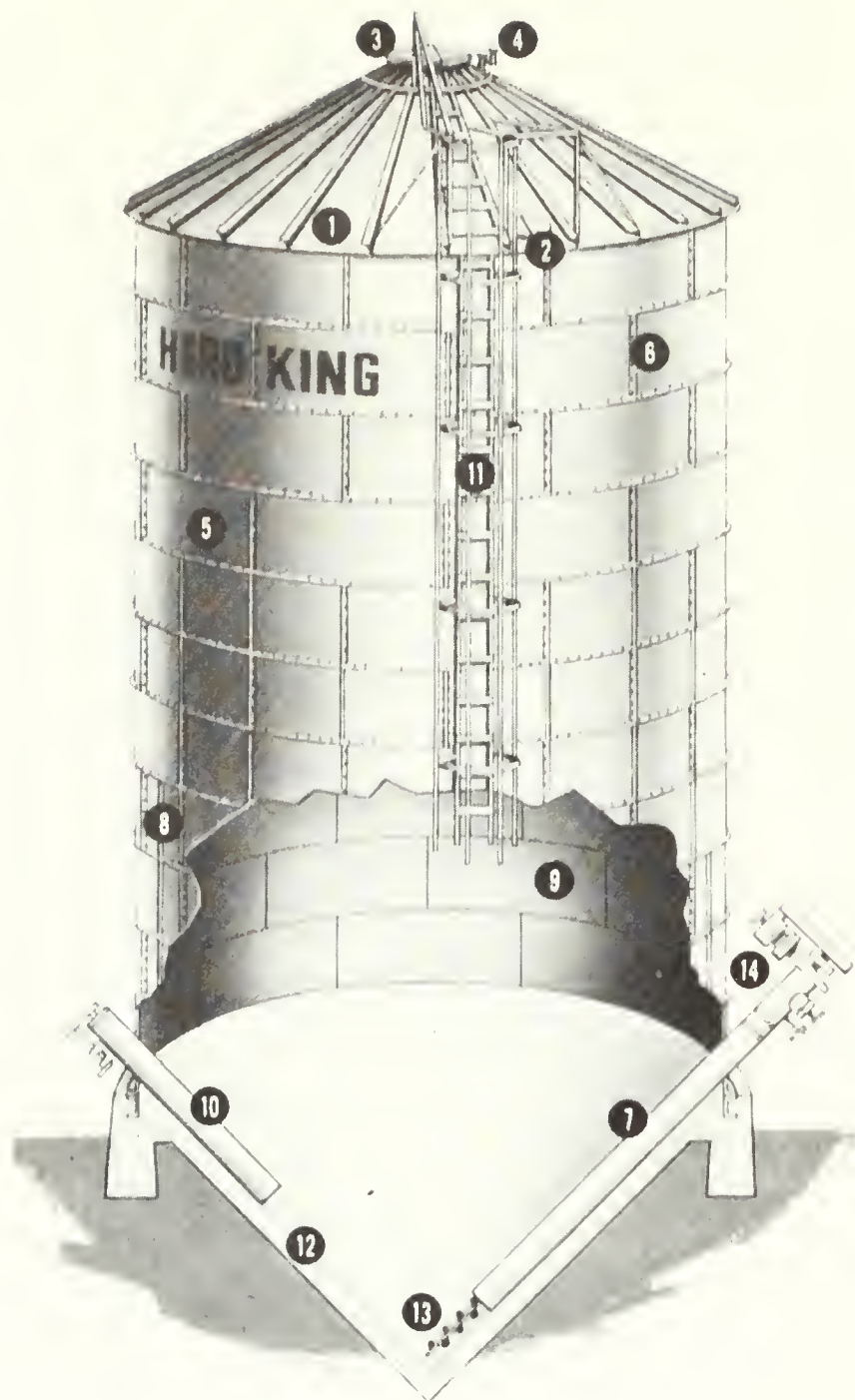
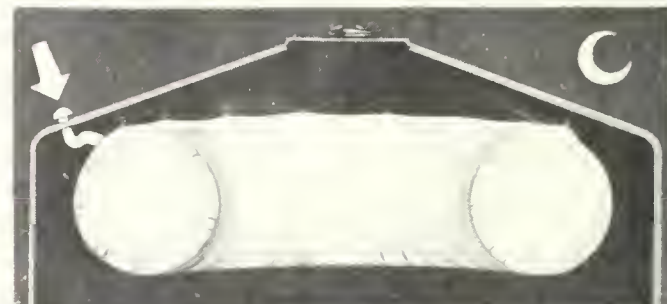
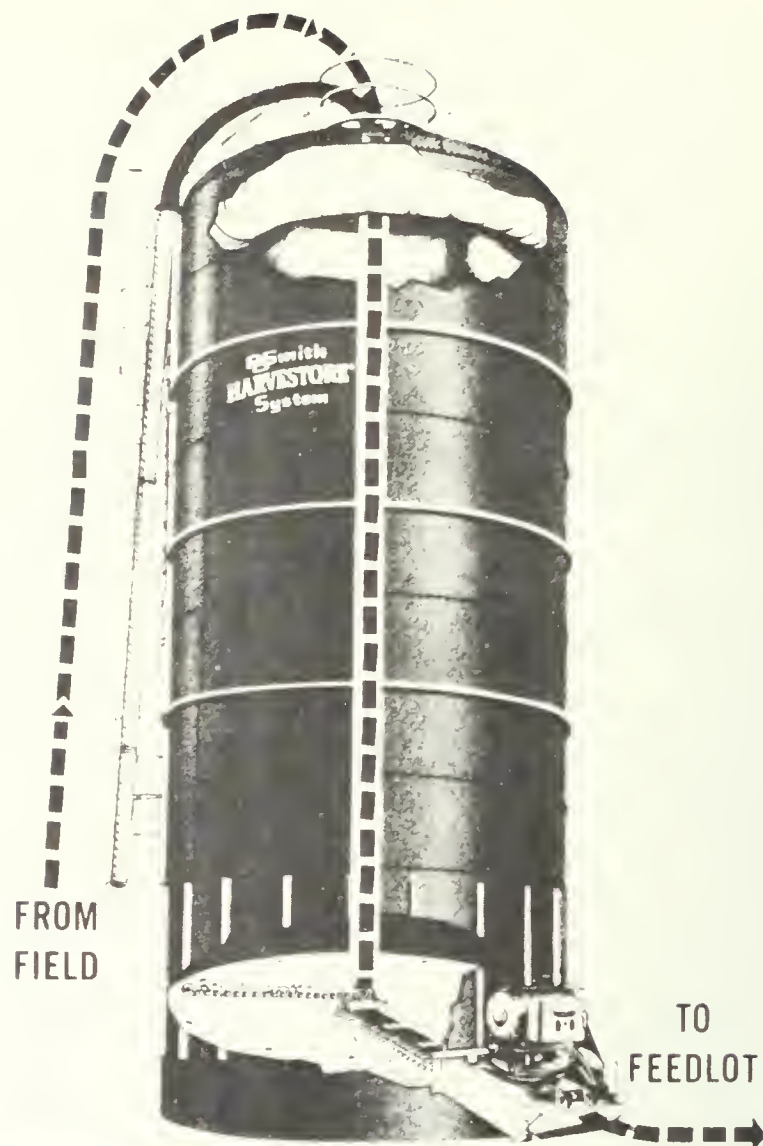


Figure 6.2.21 Oxygen-limiting steel grain storage with hopper bottom and adjustable-flow unloading auger. Courtesy, Clayton & Lambert Mfg. Co., Farm Products Division, Buckner, Kentucky.

1. Conical roof (stainless surfaced steel)
2. Sealed manhole
3. Sealed unloading door
4. Pressure/vacuum regulator valve
5. Wall panels (stainless surfaced steel)
6. Sealed wide-flange seams
7. "Adjust-a-Flo" unloading auger
8. Steel reinforcement (lower sections)
9. Smooth inside surface
10. Alternative auger tube
11. Safety ladder
12. Hopper bottom
13. Total clean out



Breather System — Pressure relief valve compensates for daily pressure variation without dilution of atmosphere inside storage structure. It is possible to mount the breather bags in the head space of a nearby feedroom, barn, or unused hayloft to increase the capacity of the silo.

Figure 6.2.22 Oxygen-limiting, high-moisture grain storage structure with chain-arm type sweep unloader and "breather system". The new "Spartan" unloader is designed to handle high-density, high-moisture grain and is similar to the "Goliath" forage unloader. An auger-type sweep unloader, with sealed valves to maintain oxygen-limiting conditions, is also available for free-flowing materials. The high-moisture storage structure is available in capacities of 215 to 545 m³.

Nominal capacities of Harvestore structures in m³

All-purpose Models

Model	m³	Model	m³	Model	m³
11B1740E	234	13B2059E	475	17B2569E	915
11B1749	291	13B8068E	555	17B2579E	1040
12B2032E	240	13B2077	630	17B2588	1170
12B2041E	320	16B2542E	525	18B2569E	915
12B2050	400	16B2551E	655	18B2579E	1040
12B2059	475	16B2560	785	18B2588	1170

Grain Models

Model	m³	Model	m³	Model	m³
20B3170E	1370	40B2028E	215	40B2042	330
20B3180E	1560	40B2033E	250	42B2534E	420
20B3189	1750	40B2038E	290	42B2543	545

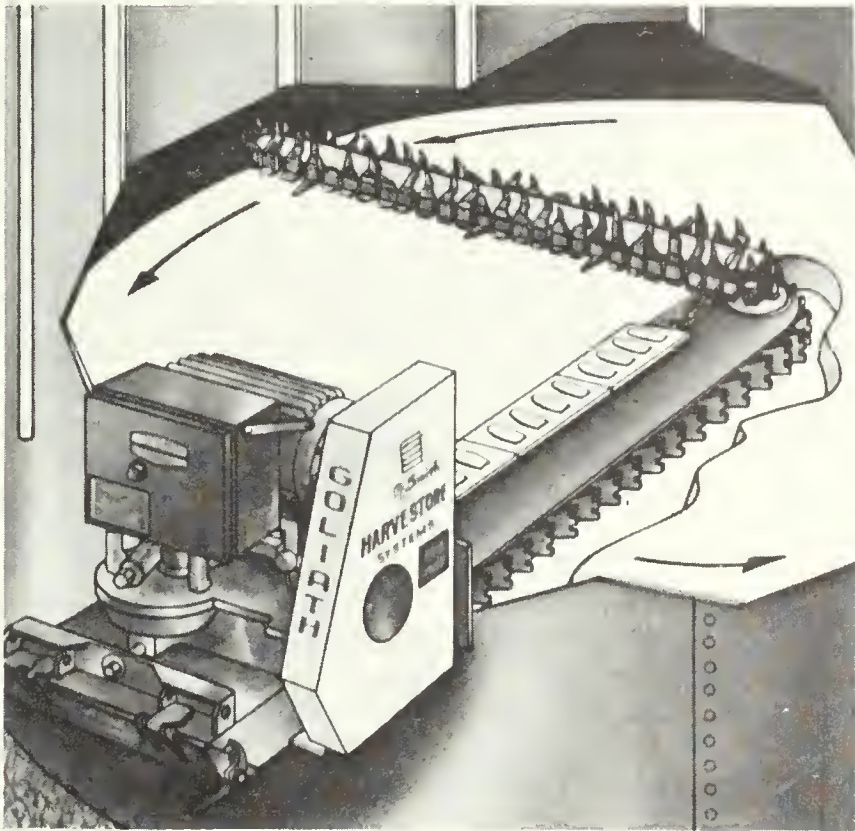


Figure 6.2.23 Goliath unloader for forage. This unit is factory assembled and mates with Harvestore structures. It is powered by a 7.5 hp, high starting torque electric motor, and is designed to unload the 6 - 7.5 m Harvestore structures. The Hercules is a lighter unit of similar design and used to unload semi-freeflowing materials, such as ground ear corn, from the 5 - 6 m storages.

6.2.3 VENTILATED-CRIB EAR CORN STORAGE

As the cost of fuel for supplemental heat drying of shelled corn continues to rise, more and more farmers are returning to naturally ventilated crib storage for ear corn.

6.2.3.1 Pressure Characteristics and Limiting Dimensions for Ear Corn Storage

Unit pressures of ear corn on crib walls and floors were investigated by McCalmont and Ashby (25). Their results, shown in Figures 6.2.24 and 25, were measured in cribs 2438, 3048 and 3657 mm in width. Because of lower average temperatures during the early storage period, corn cribs in the corn producing areas of Canada are generally limited to about 1500 mm in width for long rectangular cribs or about 2500 mm diameter for round cribs. For design of narrower cribs, unit pressures taken from Figures 6.2.24 and 25 will provide conservative estimates. Round cribs with a vertical center-ventilation opening of about 0.10 m² cross-section area, are effective up to 3000 mm in diameter.

For calculating ear-corn crib capacity, one m³ of cribbed ear corn will yield about 0.4 m³ of shelled corn.

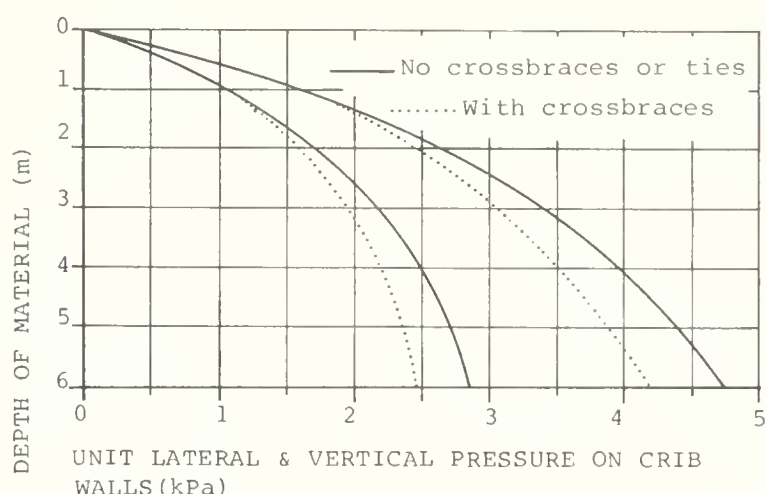


Figure 6.2.24 Cribs 2400 wide x 4800 long, coefficient of friction of ear corn on crib wall is 0.62.

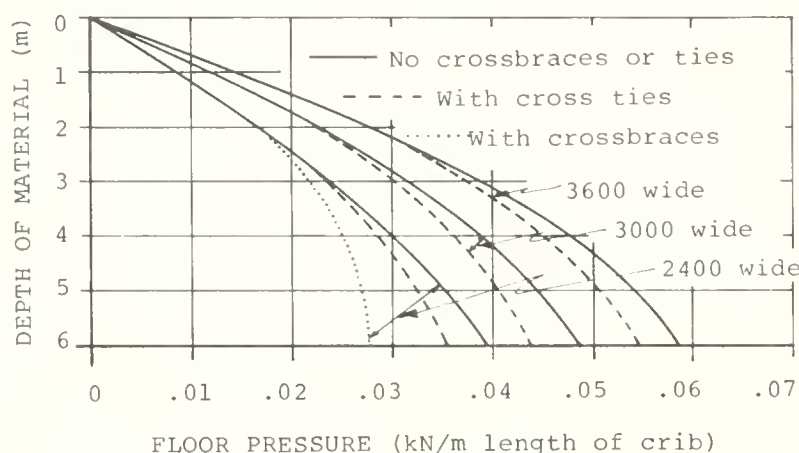


Figure 6.2.25 Floor loads in wood-frame cribs

6.2.3.2 Types of Ear Corn Storages

Temporary Snow-fence Cribs

Subject to the limiting dimensions discussed in 6.2.2.5, circular rings of standard wood and wire snow fencing can be used for ear-corn storage. The fence rings are reinforced with additional hoops or strands of 3.8 mm galvanized fence wire. The crib is set on a raised platform, usually of wood construction to prevent the corn from contacting the ground, and also to provide under-floor ventilation. Snow-fence cribs are made 2400 mm (2 rings) or 3600 mm (3 rings) in height.

In areas of heavy fall and winter precipitation, corn cribs should be roofed. The snow-fence crib, because of its round shape and temporary nature, is difficult to cover. Some farmers thatch the top of the storage with cornstalks.

The snow-fence crib is not very successful. Storage losses from birds, rodents and weather are much too high. The annual time required to reconstruct the cribs can easily justify a more permanent construction. These cribs should therefore be used only as emergency storage in years of surplus production.

Bent-strip Hardwood Cribs

Cylindrical ear-corn cribs can be made by wet-bending 15 by 100 mm hardwood strips around vertical 38 by 89 mm studs spaced 1200 mm on centers. The minimum diameter of such cribs is 3600 mm, therefore a central ventilating duct will be required. An assembly jig is used to hold the studs in a circular position while the hardwood strips are wrapped around and nailed in place.

This type of prefabricated crib does not require reconstruction for each corn crop, but it does present the same roofing problems as the snow-fence crib. A conical galvanized sheet steel roof is most suitable, but it would have to be made up especially for the small-diameter cylinder.

Manufactured circular ear corn cribs made from heavy gauge electric-welded wire mesh are also available as illustrated in Figure 6.2.26.

Figure 6.2.26 shows a popular type of construction for rectangular ear-corn crib storage. The wood strip siding can be substituted by 50 x 100 mm, 12-12 gauge galvanized welded wire mesh. The wire mesh is secured to the outside of the vertical studs with the 100 mm opening in a vertical position to prevent the ear-corn from rolling out of the openings. The material cost of galvanized wire mesh is about the equivalent of the cost of wood strips.

Ear-corn cribs with spaced wood siding and weather-tight roofs, as in Figure 6.2.27, can be easily converted to dry shelled corn storage by securing strips of 6 x 6 mm mesh hardware cloth between the studs and on the inside of the wood siding. Any new crib construction which might later be converted to dry shelled corn storage should have the hardware cloth secured to the outside of the vertical studs before the strip siding is nailed in place.

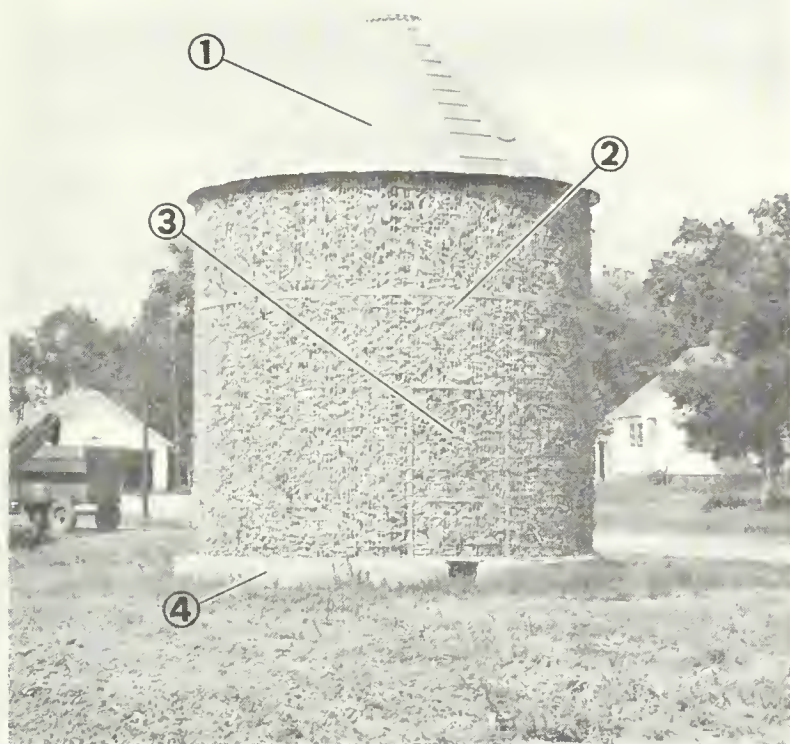


Figure 6.2.26 Factory-made welded-wire corn crib with conical steel roof. Courtesy, Behlen Mfg. Co., Inc., Columbus, Nebraska, U.S.A. (A Division of The Wickes Corporation).

1. Roof assembly, similar to steel grain tank.
 2. Steel wire, electric-welded sidewalls; 50 x 100 mm mesh, 6.7 mm wire, galvanized after welding.
 3. Access door for unloading and service.
 4. Concrete slab base (not supplied).
 5. Steel mesh ventilating tunnels and ventilators (not shown).
- Sizes available (cylindrical dimensions only)
 5 x 3.05, 4.57, 6.1 m
 3.9 x 3.05, 4.59, 6.1 m

Shelled corn produces greater pressures than ear corn, therefore additional reinforcement may be required before filling with shelled corn. A new tie-rod schedule will usually suffice.

Canada Plan Service Plan No. 7312 gives complete construction details for a corn crib 2134 mm wide having a capacity of 188 m³.

There is some justification for having the narrowest width dimension of ear-corn storage near the floor where the velocity of natural ventilating air is minimal and where fine particles in the stored grain are likely to accumulate. A good method of obtaining this feature without sloping the outside walls is illustrated in Figure 6.2.28.

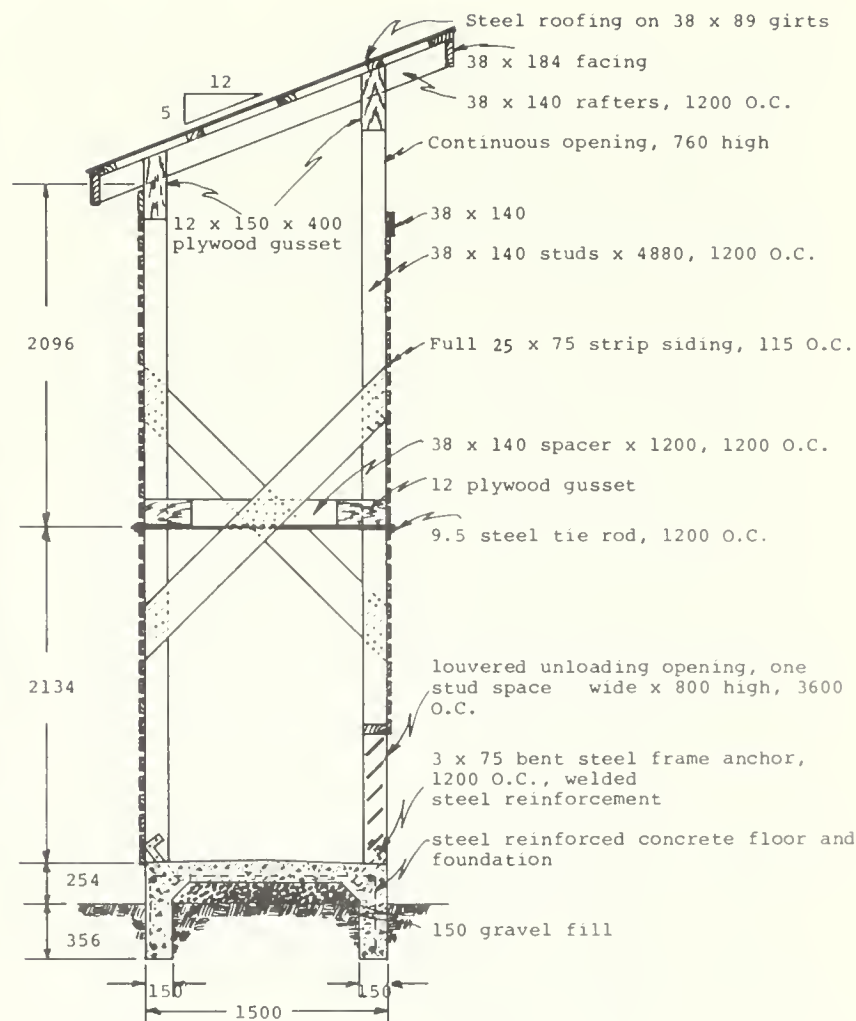


Figure 6.2.27 Rectangular corn crib vertical section, constructed with stud frame on concrete foundation.

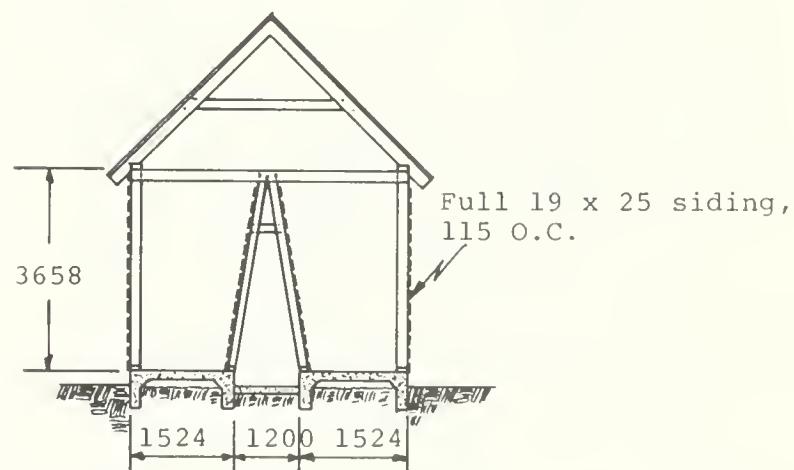


Figure 6.2.28 Double ear-corn storage crib with A-Frame central ventilation duct.

To facilitate drying the grain in this type of construction, it is advisable to place a suitable ventilating fan on the windward end of the central A frame section and to seal off the other end about 2000 mm from the end of the storage.

6.2.4 PROCESSED FEEDS AND CONCENTRATES

With the trend toward concentrated livestock production and increased specialization, an increasing number of livestock producers are processing animal feeds on the farm. The heart of these farm processing feed plants is the convenient small-size blending mill or mixer-grinder. These miniature feed mills can be automated to provide fresh feed daily for the farmer who is concerned about the improvement in palatability. They also let him change rations quickly to meet varying feed requirements, capitalize on surplus feed, conveniently add special vitamins, minerals and medication as circumstances may require, and more important, use home-grown grains without the costs of trucking grain back and forth to a commercial mill.

An important component of the on-the-farm feed processing plant is the working storage facilities for the various ingredients making up the feed ration. Several commercial firms provide a complete structure which not only includes the feed processing equipment, but surge bins overhead with gravity flow to auger-meters feeding into the blender-grinder.

Some of these structures are available in prefabricated steel components and others can be built of wood components on the site. This equipment is discussed more fully in Section 3.2, "Processing Equipment for Size Reduction and Mixing". A typical prefabricated unit is illustrated in Figure 6.2.29.

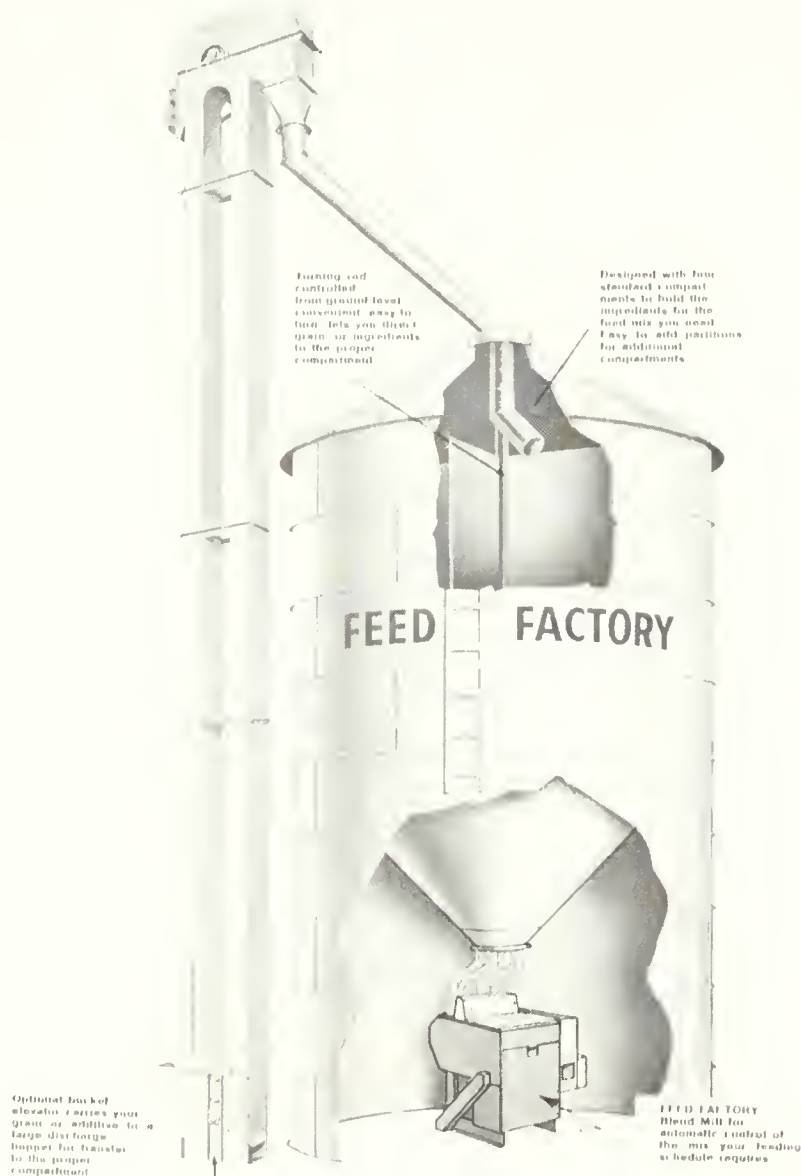


Figure 6.2.29 Prefabricated on-the-farm feed-processing plant with gravity flow surge hoppers.

In general, grains for processing and pre-mix concentrates are held in short-term storage or surge hoppers; the hoppers are filled and emptied successively many times per year. This continuous use justifies the added cost of hoppers, provided the feed is sufficiently free-flowing to permit unloading by gravity. The flow characteristics of free-flowing granular materials in shallow-hoppered and deep-hoppered bulk bins is discussed in Section 6.1., "Storage Facilities - Functional Requirements".

It is more desirable to consider all the grains that may be processed through the plant and to slope the bottoms to handle the grain with the least desirable flow properties. The most frequently used angle is 60° from the horizontal. Lining the sloping surface with sheet material which will polish with use will decrease the coefficient of friction and reduce the potential for bridging.

In theory, bulk bins hoppered eccentrically should give less trouble with bridging than bins with outlets off the bottom center. In practice, however, there is no apparent advantage to the off-center discharge for handling finely ground feeds. Where bulk bins are part of automatic systems, pelleted feeds can be used to give more reliable unloading; where unloading is attended, manual agitation in the bin by means of a suspended loop of chain may be necessary.

Because bulk bins should be smooth-surfaced and dust-tight, two structural skin materials are most frequently used for bulk bins namely, fir plywood and steel (galvanized or painted).

6.2.4.1 Plywood Bulk Bins

Wood-framed Rectangular Plywood Bins

Several bulk bin designs have been prepared by the Plywood Manufacturers Association, utilizing the plywood chiefly as a sheathing material, supported by exterior wood framing and steel tie-rods. Plans are available from most building materials suppliers. Two popular bins of this type are illustrated in Figure 6.2.30.

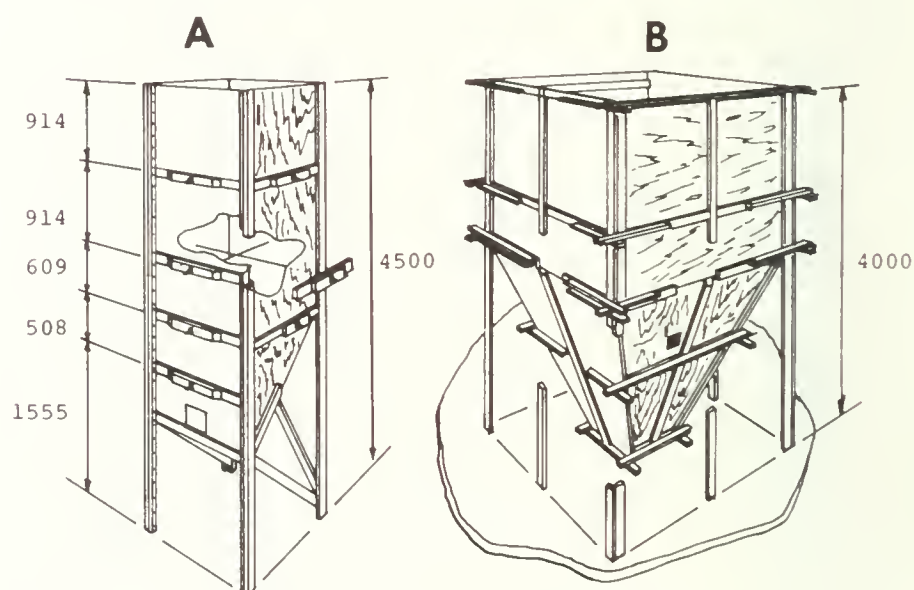


Figure 6.2.30 Bulk feed bins with lumber frames and plywood sheathing: A-single-slope side discharge, 1.8 tonne capacity; B-center discharge, 6.8 tonne capacity. Courtesy, MacMillan and Bloedel.

Bulk bins are rated by volume (m^3) or by capacity in metric tonnes. A tonne of bulk feed in storage having a density of $500 \text{ kg}/m^3$ would occupy 2 m^3 .

Finger-jointed Plywood Bins

By using a finger-joint on the extended corners of interlocking plywood sheets and reinforcing the outside corners with 38 x 38 mm lumber, the customary structural frame can be eliminated, producing a relatively low-cost storage bin. Hopper bottoms can be included to provide convenient feed storage adjacent to animal production buildings using automatic feeding equipment. By using tongue and groove plywood, no additional gussets will be required at the joints. Single bins with a cross-section of 1200 x 1200 mm and a capacity of 6 m³ or 3 tonnes are commonly used for hog and poultry production.

A 1200 mm section shown in Figure 6.2.31 illustrates the construction detail for a single bin. Four bins can be similarly constructed using full 1200 x 2400 mm plywood sheets to make four shared walls.

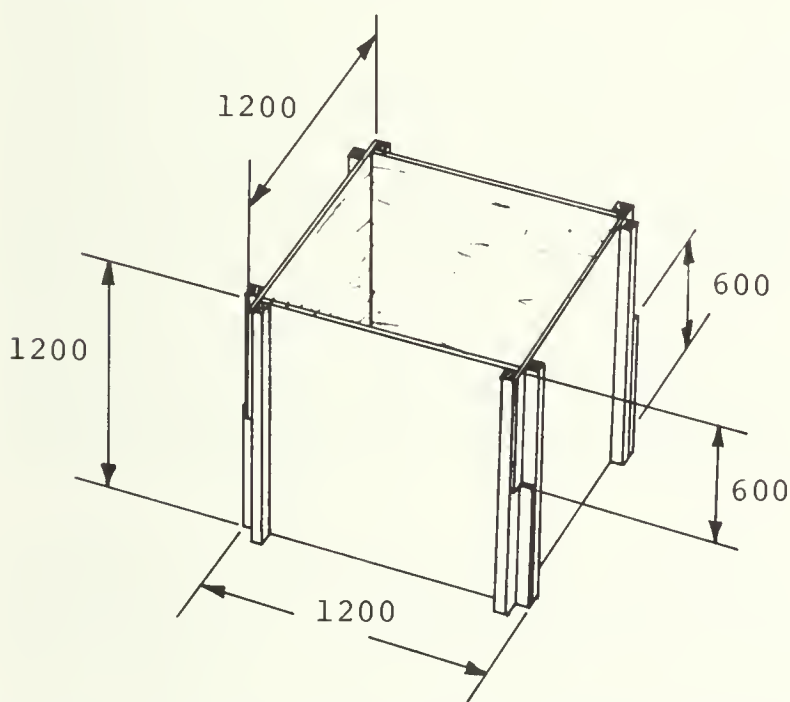


Figure 6.2.31 A 1200 mm section removed from a single-cell finger-jointed plywood bin, showing the timber reinforced glued and nailed corner construction.

6.2.4.2 Manufactured Steel Bins

The most popular type of bin for storage of mash, meals, formula feeds, pellets, crumbles, seeds and other free-flowing bulk materials is of stressed-skin galvanized steel construction. They are designed for feed dealers and every day farm storage and can be equipped for completely automatic materials handling.

They are available commercially in a variety of sizes from 4.5 to 37.5 m³ in the center draw-off tanks and from 5.7 to 42.5 m³ in the side-draw-off tanks. Center draw-off tanks are used for materials which tend to flow easily. Side draw off tanks, having one straight side, are more expensive per unit volume but promote more positive discharge.

Vertical sidewalls can be corrugated (as shown in Figure 6.2.32) to add rigidity to the container, but the sloping bottom must be smooth.

6.2.5 FORAGES AND BEDDING

Forages consist essentially of silage and hay. They are generally stored in vertical or horizontal silos and hay and bedding are usually stored in simple shelters or barn lofts of two-storey barns.

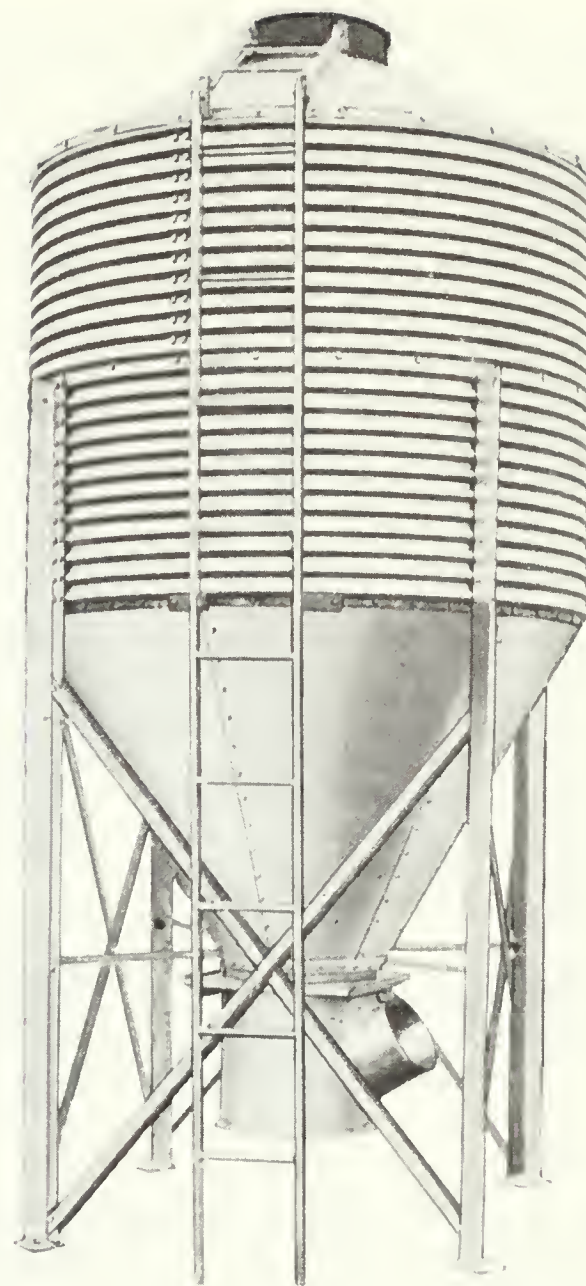


Figure 6.2.32 A typical galvanized steel bulk bin with center draw-off and special fitting under the slide valve for auger installation for automatic removal of free-flowing material. Courtesy, Westeel-Rosco Limited, Toronto, Ontario.

6.2.5.1 Vertical Silage Storage

Storage Losses

Losses of dry matter and feed nutrients in storage are highly variable because of the number of contributing factors.

Table 6.2.8 is a summary of several reports. The data are typical of the conditions prevailing at the time; where current conditions remain unchanged, the same comparative dry matter losses still apply. However, as methods of silage making improve and advances in technology for handling and storage are made the old values will have to be brought up to date. New concrete designs for monolithic and stave silo construction provide walls of greater density with lower porosity, allowing a more air-tight container ensuring less spoilage. Losses have been further reduced by proper filling techniques and the use of silage distributors to insure uniform loading.

TABLE 6.2.8 Comparative Dry Matter Losses from Conventional Tower, Horizontal and Oxygen-Limiting Silos

Reference	Conditions	Total D.M. loss %of stored D.M.
Embry et al South Dakota State College 1969	Tight concrete stave silos, plastic capped: Alfalfa silage, 60.2% M.C. Alfalfa silage, 39.8% M.C.	6.3 4.2
	Oxygen-limiting steel silo	2.0
Derbyshire et al U.S.D.A, Belts- ville, Maryland, 1962	Two 10'x40' tile silos, plastic capped, doors fitted with rubber gaskets. Wilted alfalfa storage: Silo No. 1, 1960, 58.9% M.C. Silo No. 2, 1969, 57.2% M.C. Silo No. 1, 1961, 56.2% M.C. Silo No. 2, 1961, 59.6% M.C.	8.8 4.6 11.8 8.0
Olson, Oscar E. S. Dakota Agr. Expt. Station S.Dakota	Corn silage: Concrete tower silos Stack Oxygen-limiting silos	21.0 50.0 8.0
Shepherd et al, Bureau of Plant Industry, Soils and Agr. Eng., Washington D.C.	Alfalfa grass silage: 14'x49' oxygen-limiting, 63% M.C. 10'-25' conc. stave, 63% M.C.	11.92 12.53
Voelker & Bartle, S.Dakota Agr. Expt. Stn., S.Dakota	Alfalfa silage: Oxygen-limiting silo Wood lumber silo	1.7 32.5

Design criteria

It is not our intent to discuss the basic elements of concrete silo design as this service comes with the purchase of the silo.

The design and construction of tall cylindrical storage structures, such as vertical silos, has improved considerably over the years. However, the trend toward larger diameter and greater height does present special design problems with respect to the foundations.

The very nature of the structure and its contents places the center of gravity well above the base, hence differential settlement or tilting cannot be tolerated. Furthermore, in addition to concentrating a large load to a relatively small base area, a substantial portion (from 50 to 70%) of the weight of the contents is supported by the cylindrical wall and transferred directly to the foundation. It is therefore, important that the foundation design be based on an accurate assessment of soil conditions.

M. Bozozuk (7), in reviewing the situation, has concluded that, in order to reduce costs, many tower silos are supported on ring or donut shaped concrete foundations without a floor. When the silos are filled with silage, a large part of the load is transmitted through the cylindrical wall to the foundation and the remainder is carried directly by the soil inside the ring foundation. Where the underlying soil is clay, it is compressed vertically under the weight of the loaded structure in such a manner that the applied loads are distributed to the soil over the whole area enclosed by the circular foundation. This pressure is distributed to the foundation soil in the form of a series of pressure bulbs. The size and shape, determined by elastic theory, is related directly to the diameter of the loaded area.

The maximum vertical pressure occurs immediately below the footing and diminishes to 10% of this value at a depth equal to twice the diameter of the foundation. If the applied stresses within the bulb do not exceed the shear strength of the soil the structure will be stable.

Non-uniform placement of silage during filling has caused many problems. When the load from the mass of silage is off-center the pressure bulb will be distorted. Strong winds acting on a tall silo can produce the same effect. The local over-stressing of the foundation soil may cause tilting, and unless the problem is remedied it will increase with time until the silo overturns.

Several disastrous silo foundation failures have further shown that the conventional unreinforced ring footing can break into segments. According to Turnbull et al (39), this demonstrates the value of using circumferential steel reinforcing to resist bending movements and pressures developed by the weight of the silo, the load of the silage and the reaction of the supporting soil under the footing.

Good design procedure requires a knowledge of the soil bearing capacity and the loads imposed by the silo and its contents. The latter can be computed, and should be based on the heaviest high-moisture silage (70% moisture content). The type of soil and its corresponding soil bearing capacity can only be determined accurately by a soil test. Furthermore, these bearing capacities must be based on wet soil conditions which may differ considerably from those observed at the time of construction.

At present there are two types of foundations being recommended depending on the size of the silo and the general soil conditions:

1. Circular spread or "balanced ring" (14) footings of steel reinforced concrete, balanced under the silo wall.
2. "Reinforced extended-ring foundation" (37) with spiral torsion reinforcing, located predominantly outside the silo wall.

The former requires the least concrete and steel, but is based on assumed uniform soil reaction pressures, which may not be true. The latter is a safer design for large silos where the pressure distribution may be non-uniform and may develop moments for which the balanced ring would not be reinforced.

Since the trend is to larger capacity silos, the reinforced extended-ring foundation design is presented.

Reinforced Extended-ring Foundation

Turnbull et al (39) have shown that the proper use of reinforcing steel in a ring footing makes it possible to position most of the foundation or footing beyond the circumference of the silo wall, thus providing a wider base to improve stability. And, with less concrete than in conventional footings, it still provides a greater total area to support the weight of the silo and its contents. The floor of the silo inside the footing may consist of inexpensive gravel (for drainage) and polyethylene film (to prevent seepage).

The reinforced extended ring foundation is shown in Figure 6.2.33. Footing width B depends on the weight of the silo and its foundation as well as the equipment, the friction load of the silage as it settles against the silo walls, and the soil bearing capacity.

The Canadian Farm Building Code (36) gives a rule for estimating that part of the silage which would be supported by wall friction: "...vertical wall friction may be approximated by assuming that the wall at its base supports the weight of silage above a right circular cone with the cone base being the floor of the silo and height 4.72 times the silo diameter."

The charts in Figures 6.2.34 and 6.2.35 show the footing dimensions B (width) and d (depth) for soils having bearing capacities of 96, 192 and 288 kPa. Soil bearing capacities should be determined from deep soil tests by a civil or agricultural engineer.

The charts also give the required spiral steel area (A_s) to resist footing rotation and circumferential steel area (A_L) to resist lateral pressure based on 20.7 MPa concrete and 345 MPa steel yield point. It is very important to locate the steel near the bottom of the footing, as shown in Figure 6.2.31, to make the footing act like a circular beam. This prevents the vertical load of the silo wall from turning the footing outwards at the bottom.

The number of turns of spiral rebars must be calculated to provide the required section area. For example, assume a 9.14 m diameter, poured concrete silo with a total wall height of 22 m on soil having a bearing capacity of 144 kPa. From Figure 6.2.35, the required footing width, $B = 1.6$ m, thickness $T = 68$ cm, spiral steel $A_s = 8900$ mm² and $A_L = 800$ mm².

Further details for reinforced extended-ring foundations for 150 mm cast-in-place and 62 mm concrete-stave tower silos can be obtained from Plans 7411 and 7412 respectively, of the Canada Plan Service.

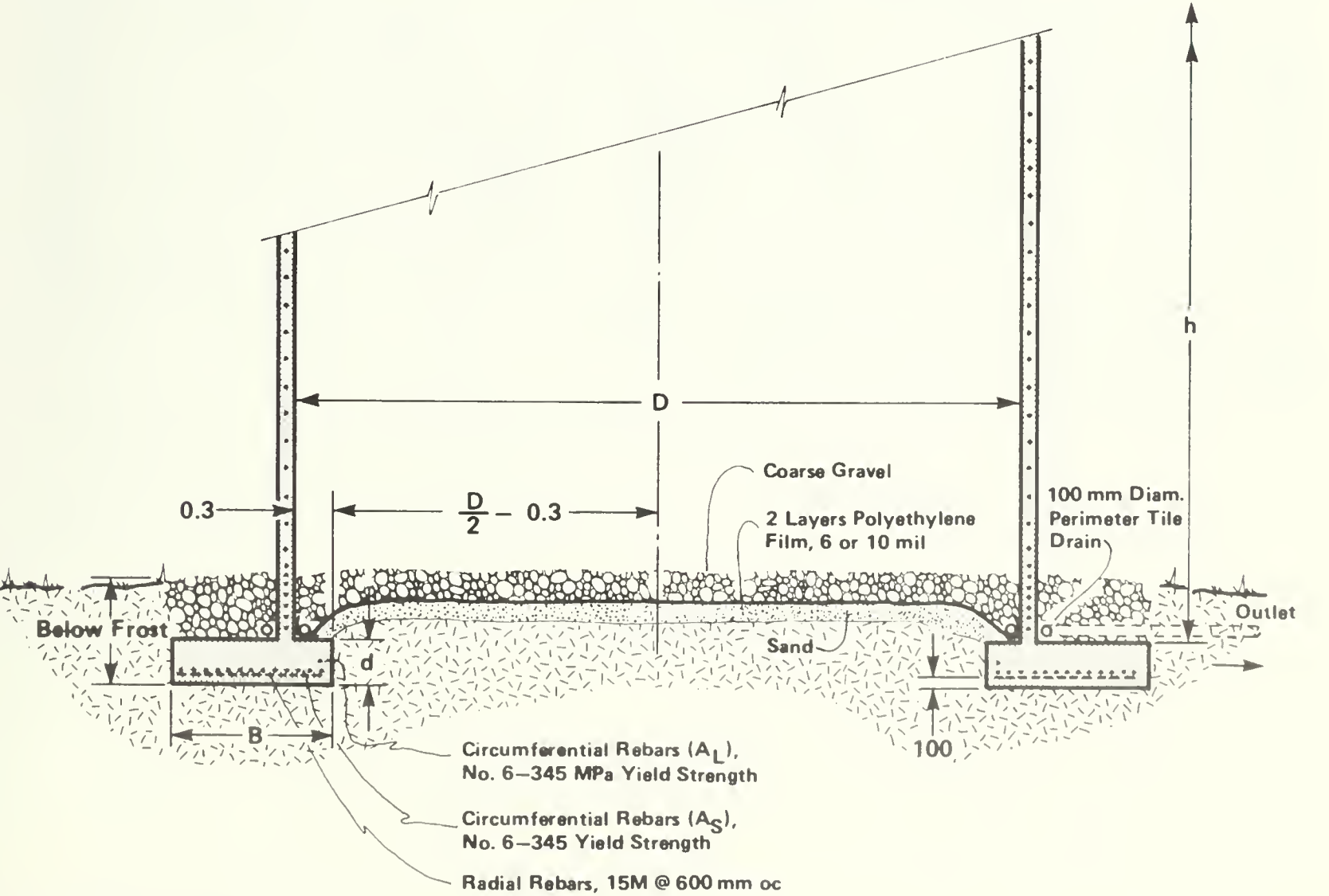


Figure 6.2.33 Section of reinforced extended ring foundation.

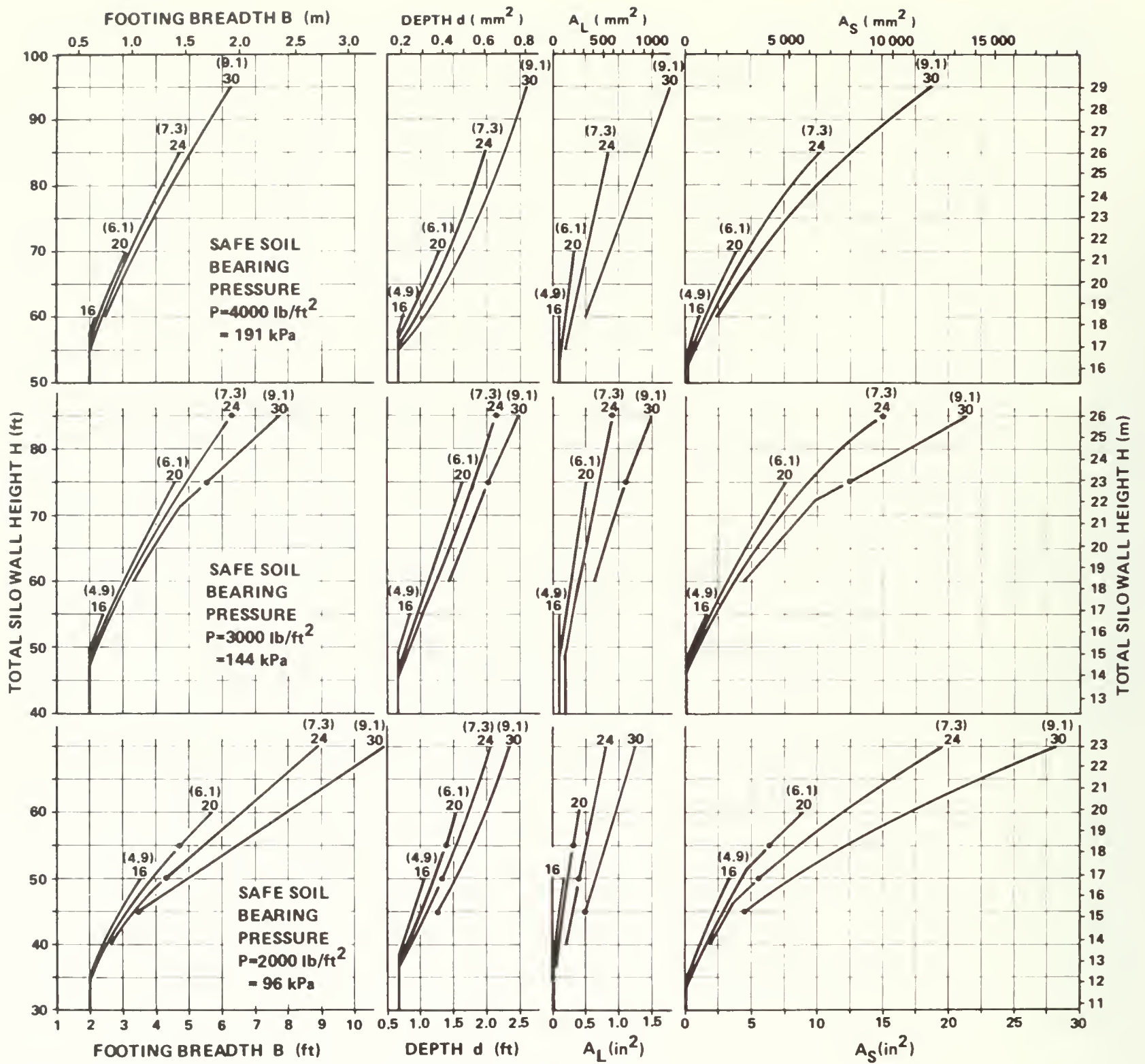


Figure 6.2.34 Design of torsion ring foundation for concrete stave tower silos.

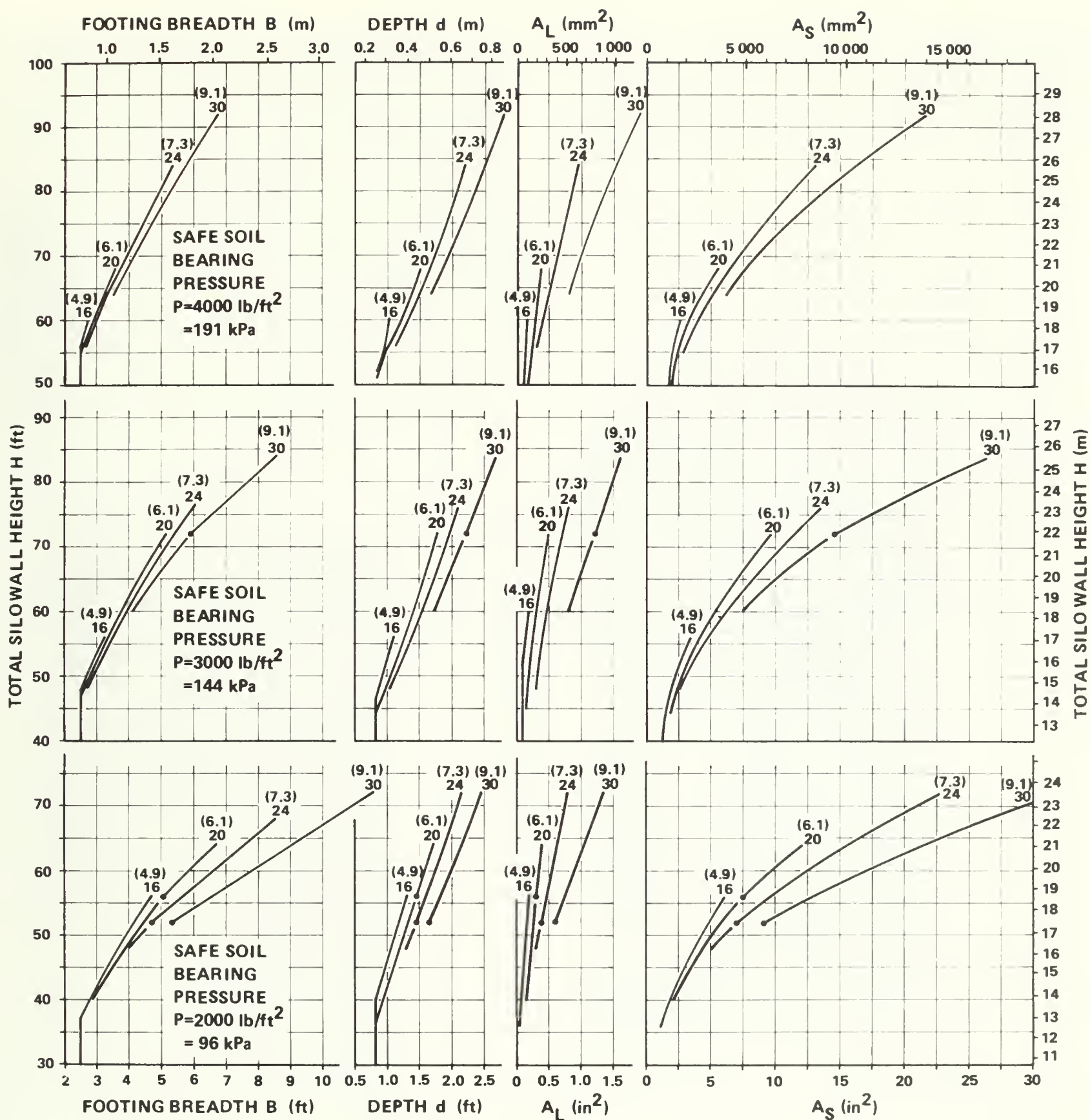


Figure 6.2.35 Design of torsion ring foundation for cast-in place concrete tower silos.

Selection of Required Silo Dimensions

Minimum silo height is determined chiefly by the minimum daily feeding rate, which will control spoilage, times the number of days in the feeding period. The feeding rate is dependent on the material stored and the weather conditions; Table 6.2.9 may be used as a guide.

TABLE 6.2.9 Daily Feeding Rate To Control Spoilage (Depth in cm)

Material stored	Weather	
	Cold	Warm
Whole corn	5	10-15
Alfalfa-brome	5	7-10
Chopped ear corn	5	5
Cracked shelled corn	10	10

Embry (16) has observed that a mechanical top unloader helps to control surface spoilage by removing a uniform layer each day and by leaving the surface as undisturbed as possible; this is especially applicable to low-moisture forage and ensiled grains.

In calculating silo height, allow at least 3 m of extra height for settling and for storage of the top silo unloader.

The capacity of a silo depends mainly on its height and diameter. Other factors are moisture content of crop when ensiled, length of cut, rate and distribution of filling, amount of grain in corn silage, and maturity of crop. The moisture content is perhaps the most influential factor, but the capacity of the silo on a dry matter basis is reasonably consistent within the range of 50-70% moisture. Table 6.2.10 gives the average density of whole-plant silages in tower silos. This table is adapted from data by the Ontario Silo Association - Standards for concrete tower silo construction.

TABLE 6.2.10 Average Densities of Whole-plant Silages in Tower Silos

Depth of settled silage, m	Average silage density of depth indicated, kg/m ³	
	70% moisture, whole-plant silage	
	Dry matter density	
8	625	188
10	689	207
12	747	224
14	800	240
16	852	256
18	905	272
20	942	283
22	977	293
24	1014	304
26	1044	313
28	1057	317
30	1100	330

TABLE 6.2.11 Approximate Dry Matter Capacity of Silos

Depth of settled silage, m	Silo diameter, m					
	5	6	7	8	9	10
	Dry matter, t					
8	30	43	58	76	96	118
10	41	59	80	104	132	163
12	53	76	103	135	171	211
14	66	95	129	160	214	264
16	80	116	158	206	261	322
18	96	138	188	246	316	385
20	111	160	218	285	360	445
22	127	182	248	324	410	506
24	143	206	281	367	464	573
26	160	230	313	409	518	639
28	174	251	342	446	565	697
30	194	280	381	498	630	778

To estimate tonnes of wet silage, multiply as follows;

$$\text{tonnes dry matter} \times \frac{100}{\text{estimated \% dry matter}} = \text{tonnes wet silage}$$

Oxygen-limiting Silos

As shown in Table 6.2.8, tower silos with an effective gas-seal can control dry-matter losses in stored silage to 2-4%; conventional concrete silos, properly managed, average about 10% dry-matter loss. The extent to which the extra cost of the gas-tight silo is justified will depend on the cost of producing the feed to be stored.

1. Bottom-unloading Oxygen-limiting Silos: These are sealed storage structures of concrete, fiberglass or steel which are filled from the top and unloaded from the bottom. Figure 6.2.36 shows the unloading system for one type of bottom unloader. As the forage is removed from the base of the column of stored material, the entire mass slides down the silo. This feature insures that the oldest material in the silo is always removed first.

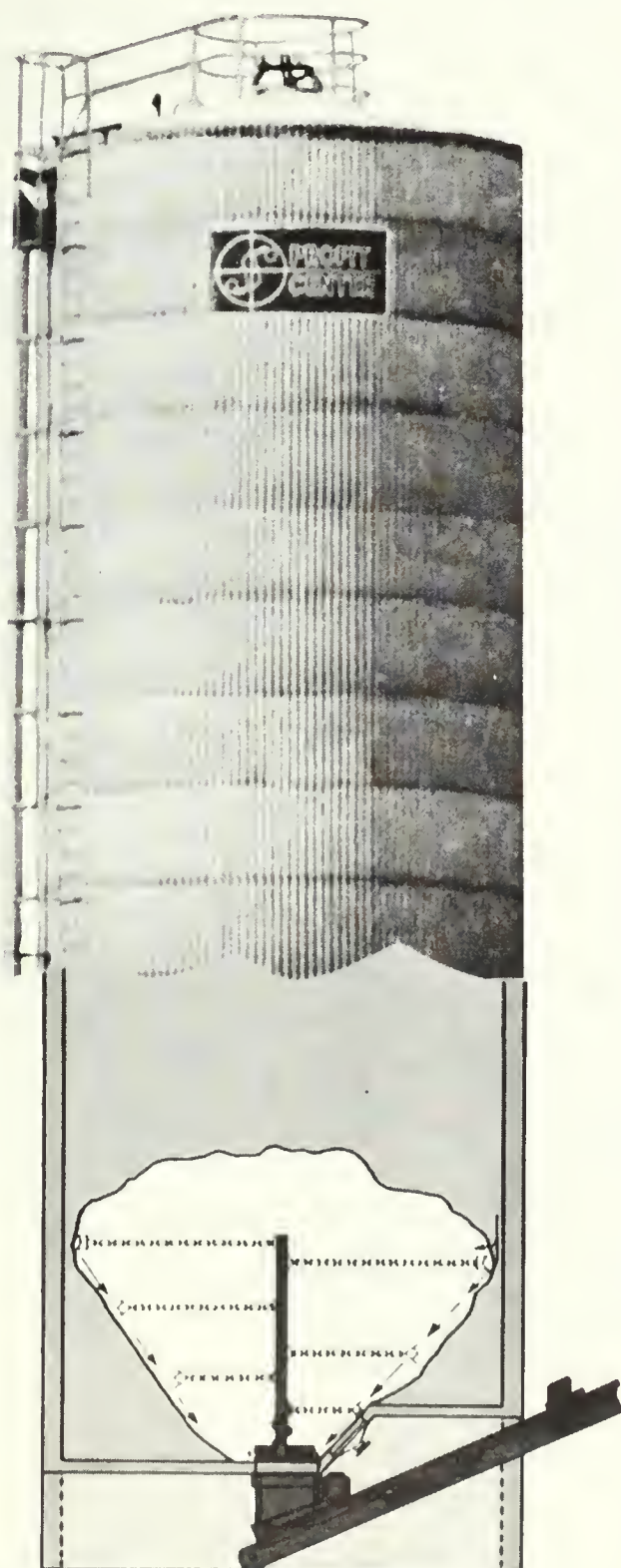


Figure 6.2.36 Flail-chain type bottom unloader.

2. Top-unloading Oxygen-limiting Silos: A gas-tight silo, of flanged panel steel construction, has been developed which can be unloaded from the top of the stored silage column. This unit is illustrated in Figure 6.2.37, and is available in three diameters, namely 6.40, 7.57 and 9.30 m, and in the following heights: 9.14, 10.67, 12.19, 13.72 and 15.24 m.

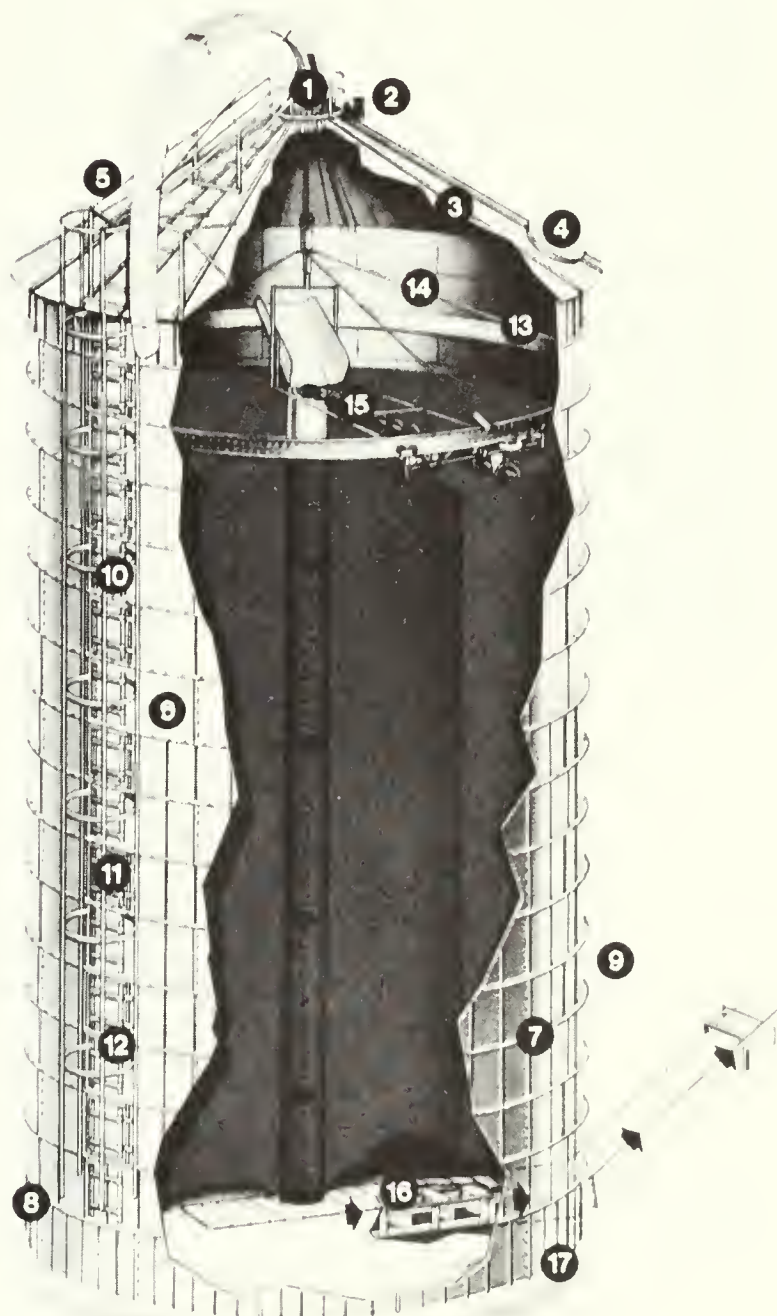


Figure 6.2.37 Oxygen-limiting steel silo with combined spreader-unloader at top of silage.
Courtesy - Clayton and Lambert Mfg. Co.,
Buckner, Kentucky, U.S.A.

1. Air-tight roof
2. Manhole
3. Filling hatch
4. Pressure regulator valve
5. Steel plug, used to form center hole during filling
6. Unloader gathers silage into center hole
7. Stored material
8. Center hole
9. Air-tight bottom conveyor
10. Bolted, air-tight seams
11. Extra reinforcement for louver panels
12. Silo doors 1500 o.c.
13. Ladder

6.2.5.2 Horizontal Silage Storage

Storage Losses

Hogland (22) stated that forage should be stored in horizontal silos at about 70% moisture content for minimum losses. Traditionally, losses in uncovered horizontal silos have been as high as 32% (Table 6.2.8); these values are usually quoted for small self-feeding silos with a large surface-to-mass ratio. However, with large intensified cattle operations where large tonnages have small surface-to-mass ratios, the actual percentage loss is considerably reduced even though the depth of spoilage may be the same in each case. The actual losses can be reduced by as much as 50% by sealing the silage with an air-tight cover, such as polyethylene, properly weighted down and protected from puncturing.

Dimensional Requirements

Horizontal silo walls should have an outward slope of 5-6° from the vertical; this helps prevent an air space from forming between the silage and the side walls as the silage settles. The bottom width should be not less than 3.5 m for ease of packing with a farm tractor. Obviously the wider the silo, the lower the unit cost. If cattle are to be self-fed from the silo, the compacted depth of silage should not exceed 2 m. However, if the horizontal silo is to be unloaded by mechanical means, the compacted depth is only limited by the capability of the mechanical device. For the normal front-end loader, 3 m is a convenient depth although some equipment is designed to unload depths up to 6 m.

To control spoilage during the feeding period, horizontal silos should feed out at a rate of 100 mm of feeding face per day. Therefore, for a 200-day winter feeding period, the silo should not exceed 20 m in length. The width of the silo will depend on the number of animals and the rate of feeding in kg per day. For rough approximation, the capacity of horizontal silos should be based on a silage density of 560 kg/m³.

Horizontal Pressure Characteristics

Esmay and Brooker (17) measured lateral pressures in horizontal silos. They recommended that walls for horizontal silos be designed for a distributed normal pressure of 4.70 kPa regardless of depth, plus a point load of 180 kg due to the wheel of the packing tractor.

Typical Horizontal Silos

1. Below-grade Horizontal Silos: When horizontal silos first came into use following the Second World War they were simply trenches bulldozed into a hillside. Many of these became nothing more than catch basins for surface runoff and snow accumulation. It was soon found that these trenches required a concrete floor to permit drainage and to facilitate the use of mechanical removal equipment. Later improvements included concrete sidewalls (Figure 6.2.38).

2. Above-grade Horizontal Silos: In areas of flat terrain and high water tables, horizontal silos must be constructed above grade. Either steel-reinforced concrete or lumber can be used; see Figures 6.2.39 and 6.2.40.

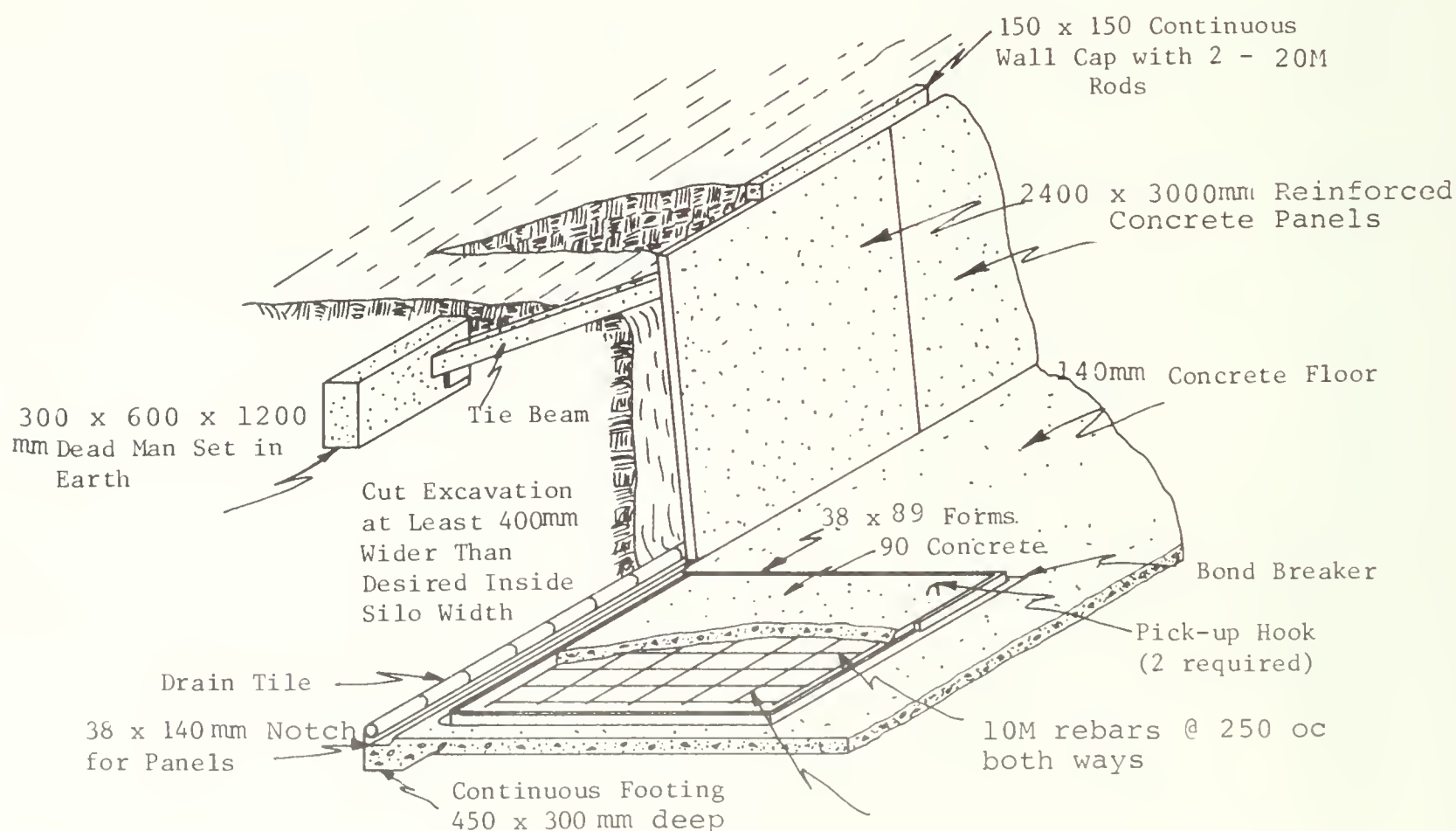


Figure 6.2.38 Below-grade horizontal silo with tilt-up concrete side walls.

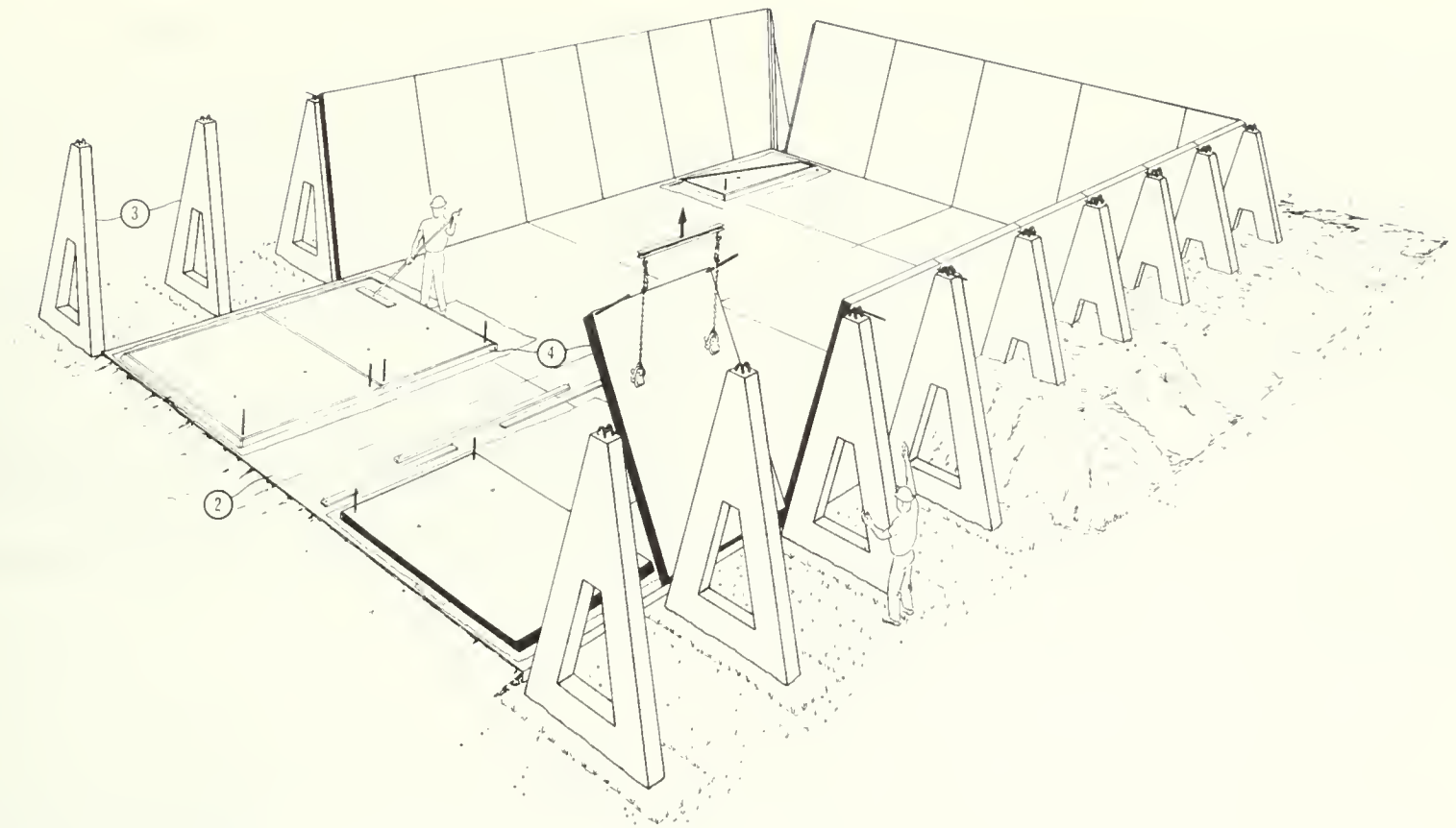


Figure 6.2.39 Above-grade steel reinforced concrete tilt-up horizontal silo (Ref. Canada Plan Service, Plan 7435).

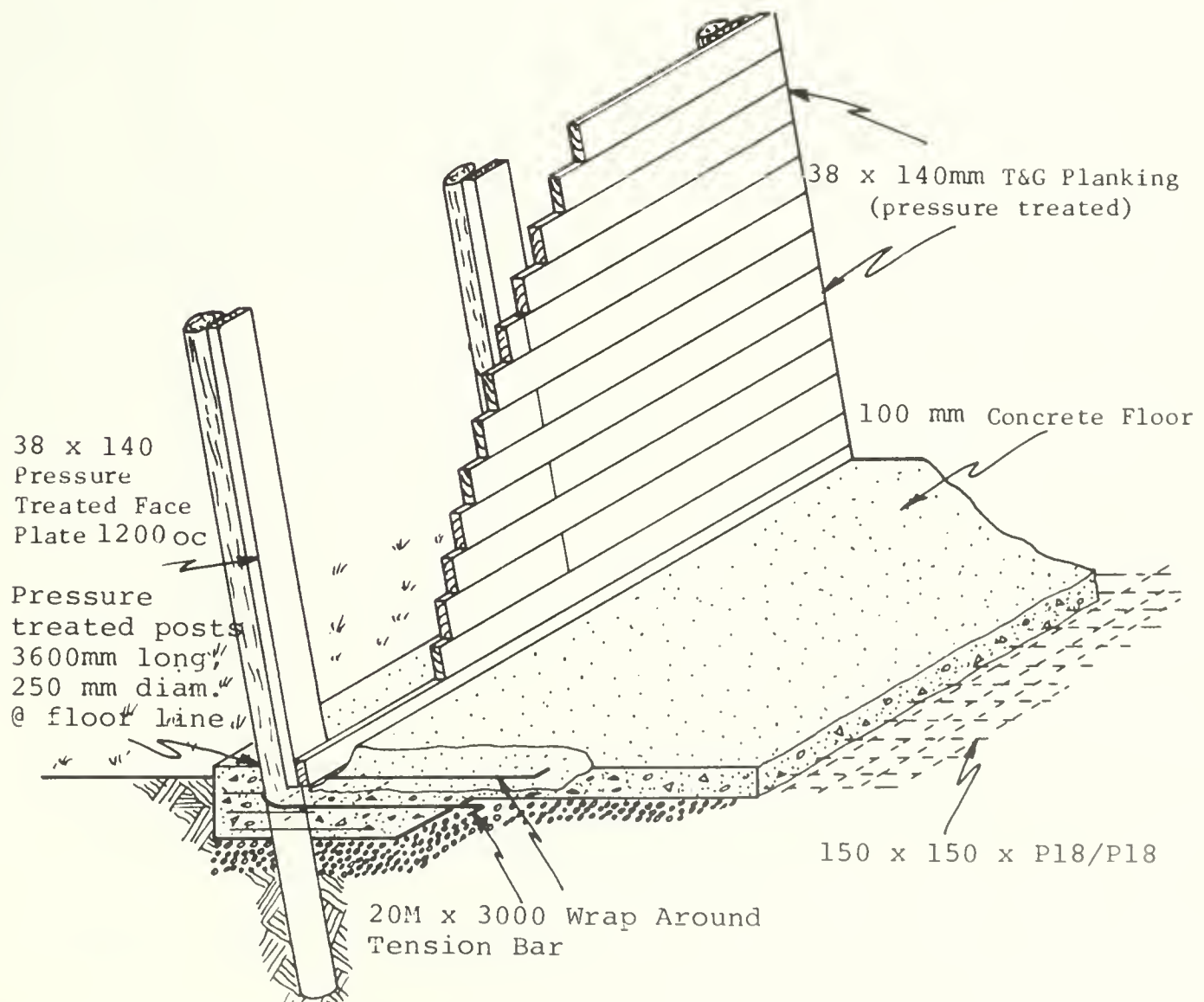


Figure 6.2.40 Above-grade, post and lumber type horizontal silo (Ref. Canada Plan Service, Plan 7431).

Earth banks above grade can be used, provided the outside slopes are grassed and the inside slopes are covered with straw, cornstalks, etc., to control erosion (see Canada Plan Service, No. M-7437).

Some farmers have expressed a desire to provide a permanent roof over the self-feeding horizontal silo. This can best be combined with the post-type horizontal silo. In this application the pressure-treated posts are placed vertically and extend above the top of the silo wall to provide sufficient clearance for a tractor and operator to compact the silage at filling time. Plate scams are secured to the top of the poles and support clear-span, prefabricated wood trusses that form the framework for the roof.

Precast Horizontal Silos

A new concept in precast horizontal silo construction has been developed by a firm in Southwestern Ontario. The basic component is an L-shaped section with the horizontal member approximately 2 m in length, the

upright member approximately 4 m, and the component length about 2.5 m.

The farmer must prepare a level site with good drainage and 300 mm compacted gravel base. The company delivers the components to the site and assembles the components in two parallel facing rows at a distance corresponding to the desired width of the silo.

Wall panels are interlocked by a concrete key and are held together at the top by a mechanical clip. A concrete floor is poured between the panels which secures the components at the base.

No on-site formwork is required, the same basic unit is used for any desired width or length of silo and may also be used to close one end. Right- and left-hand 45° sections are required to close in the corners.

A cross-section of a typical component is illustrated in Figure 6.2.41.

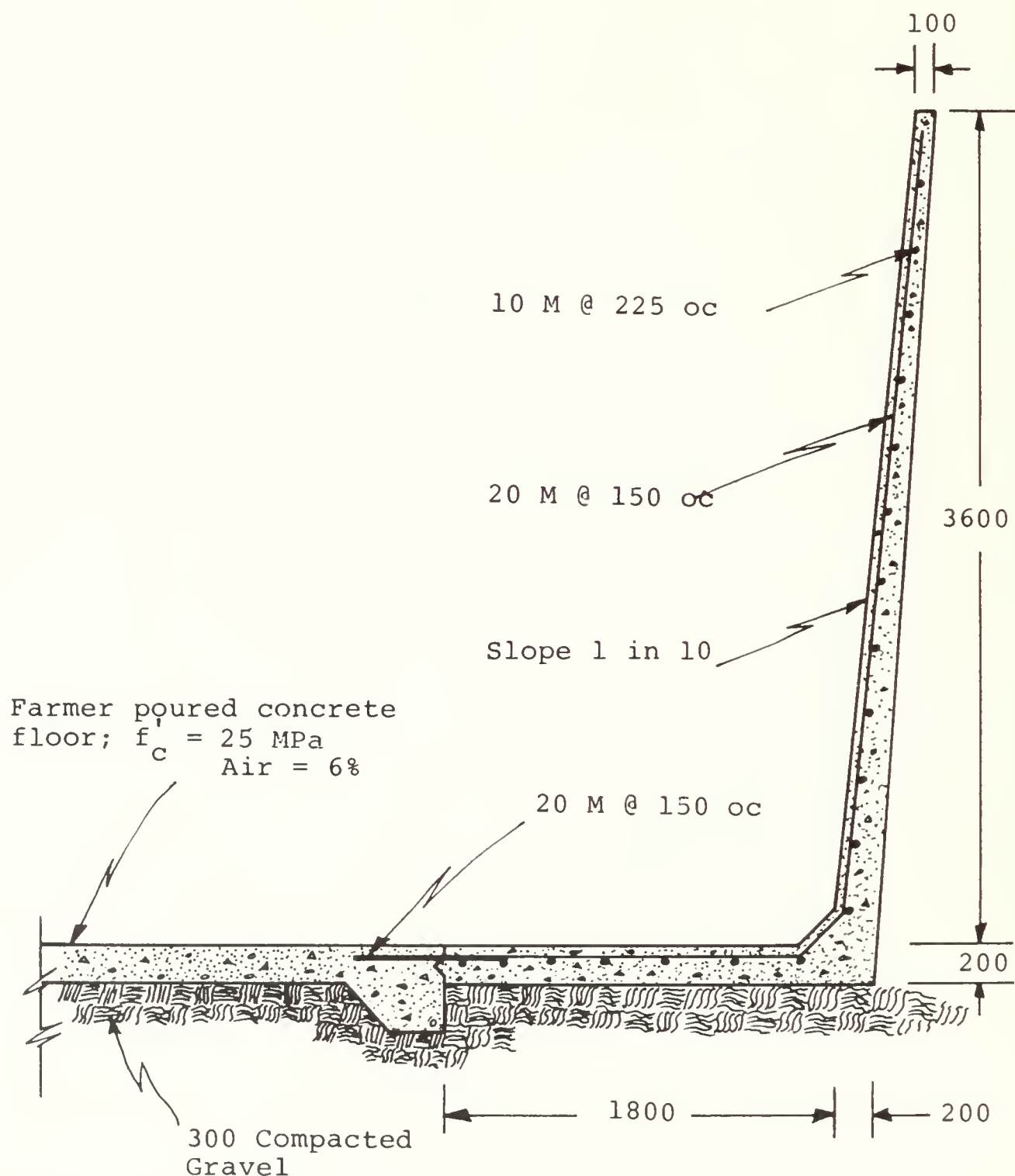


Figure 6.2.41 Section detail for a typical component of a precast, concrete, horizontal silo.

Self-feeding Gates for Horizontal Silos

Movable feed gates are designed to control wasting of feed where cattle are self-fed at the storage site. Two styles are shown in Figure 6.2.42, rear braced (A) and front braced (B). Both are suitable for horizontal silos and are built on skids to prevent overturning. The rear-braced style has long skids which are pushed back into the feed for support; the front-braced style is kept upright by the weight of the cattle standing on the front platform.

Proper management is required to control wasting of feed; with gates positioned too close to the feeding face of the stack, cattle will pull feed through gate openings and some of it will be trampled underfoot and wasted. For best results, feed should be removed from the feeding face and placed on the floor behind the gates. This way, cattle must tilt their heads through the openings and feed in a natural head-down position. Move the feed gate toward the stored

feed whenever the feeding face is too far away for easy handling and when the loosened feed on the floor is used up. Some cattlemen are concerned that the animals may not obtain sufficient feed if they have to work too hard to pull it directly from the compacted storage. Several mechanical devices have been developed to automatically cut the face of the stack. One commercial unit is available that will blend the concentrate feed with the silage.

The tombstone fixed feeding fence, illustrated in Figure 6.2.43, has become a very popular self-feeder for roughages. It provides a comfortable head-down feeding posture for the animals, and feed wasting is minimized because the plank uprights force the animals to lift their heads up before backing out, making it impossible to pull feed through the fence.

It should not be difficult to bolt this design to vertical pipes that are securely braced and welded to movable skids.

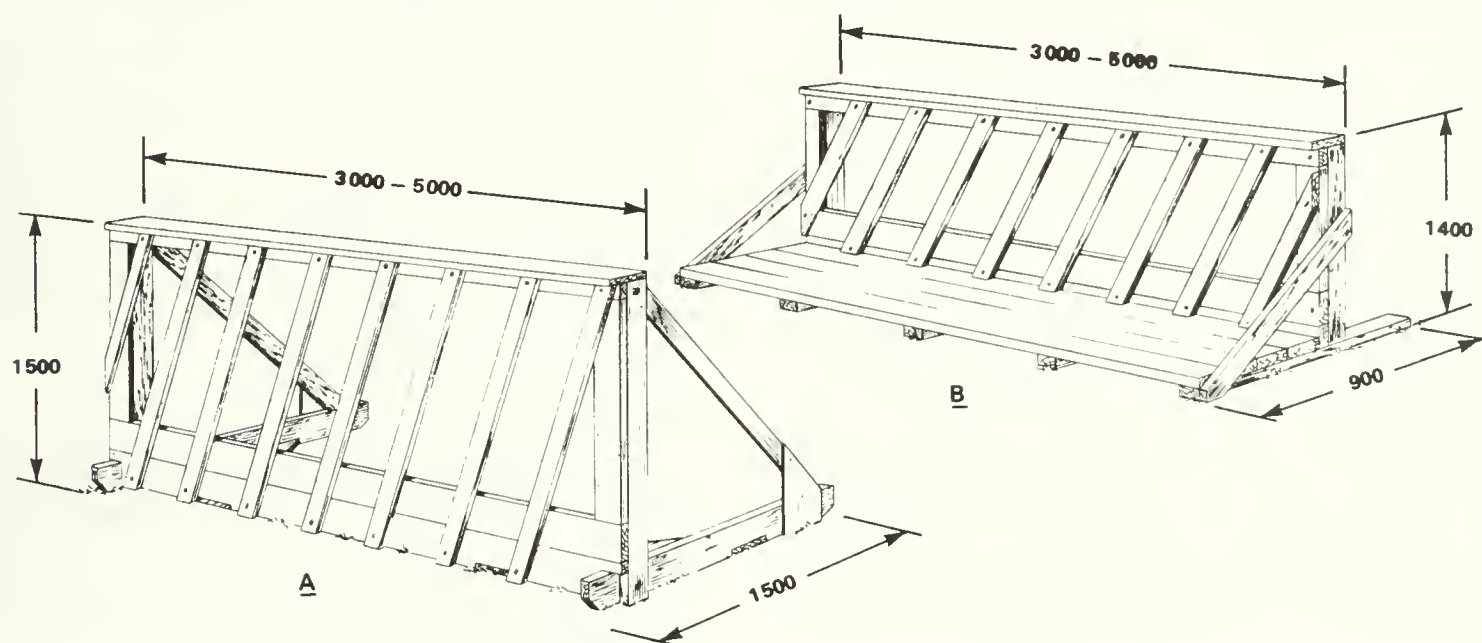


Figure 6.2.42 Two styles of movable feed gates "A" Rear Braced and "B" Front Braced. (Ref. Canada Plan Service, Plan 1645).

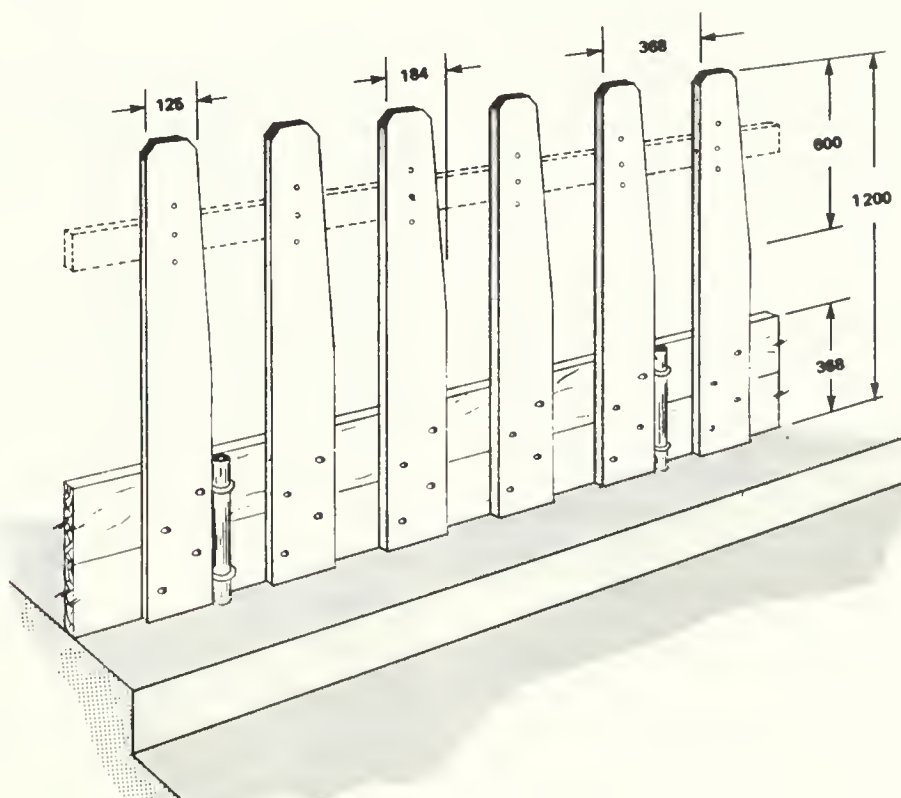


Figure 6.2.43 A typical tombstone fixed feeding fence (Ref. Canada Plan Service, Plan M2658).

6.2.6 FARM MACHINERY STORAGE

With the high capital cost of farm machinery on the modern farm, a well-planned storage and repair shop is essential. The orderly accommodation of field equipment not in use or awaiting repair will give the appearance of an efficient farm operation. Greater efficiency and convenience can be expected if traffic lanes and work areas are kept free of unnecessary machinery.

Storage costs for today's equipment are relatively low if compared to depreciation costs of the original new equipment. There is value and satisfaction in the "well cared for" look of equipment stored under cover.

Location and Orientation

1. The machine shed should be readily accessible to all parts of the farm and convenient to the farm home, but with sufficient separation, 30-60 m, for fire protection. It should be close to the farm workshop, or the shop could be located in the shed providing the necessary safety precautions are observed (see Fire Protection).
2. Utilize that portion of the farmstead in the direction of the prevailing winds as there are few odors, noise, or dust from stored equipment.
3. Gravel or hard surfaces in front of south-facing doorways dry quickly after rains or spring thaw. East facing doorways are the next best compromise between dry roadways, wind protection, and accessibility.
4. Outdoor storage areas are best located behind the shop or shed, and away from the farm home.
5. Conceal the unattractive appearance of outdoor or general storage areas with dense-growing hedgerows such as caragana, lilac, honeysuckle and chokecherry.
6. Drifting snow will accumulate up to 36 m from a fullgrown shelterbelt. Place only equipment and materials not used in winter close to the shelterbelt.

Space Requirements

1. Outdoor: This will vary with the scale of operation and the degree of on-farm mechanization. However, an area of 30 x 60 m will accommodate most of the big machinery on large-scale operations. Additional space should be provided to maneuver awkward machines and also serve as an alleyway. Some space should be provided beside the machine shed to permit the parking of one large machine that may be in current use. Do not take up space in front of the workshop.
2. Indoor: The usual procedure is to cut out cardboard silhouettes (to scale) of all the major equipment to be placed in storage. A good reference for the areas and dimensions of farm vehicles and equipment is the Canadian Farm Building Code (36). Arrange the cutouts (interlocking equipment where possible) in a rectangular shape and use all available space, but keep in mind that the first equipment to be used in the spring should be the last put into storage in the fall. Then, using the same scale as the cutouts, determine the overall dimensions of the required storage.

Trucks and tractors are most frequently used and should occupy the center area near the main access door. Since the overhead clearance varies in some buildings, tall equipment should be placed in the center and low equipment such as harrows, windrowers or grain drills should be placed on the side.

Building Type

Traditionally machine sheds were long and narrow with one side completely open for ready access to stored equipment. However, snow could drift in easily and the protection was not much better than outdoor storage. Doors were too expensive and inconvenient. The modern structure is much wider with a central service alley and is completely enclosed. It has a minimum number of doors, usually one at each end and a drive through the side.

A variety of structures are available to supply the needs of an inexpensive machine storage including:

1. Steel quonset (frameless)
2. Arch-rib (clear span laminated wood)
3. Rigid frame (Comp-O-Bilt, prefabricated) (33)
4. Steel arch frame (clear span)
5. Pole frame or stud wall (with clear span trussed rafter)
6. Gambrel roof braced rafter arch frame

The first four types are all clear span construction with higher clearance at the ridge. The overhead clearance of type 5 is restricted to eave height; and the walls may have to be extended to accommodate the tallest machine. Detailed plans for pole-frame machinery storage with end-opening or side-opening doors may be obtained from the Canada Plan Service (Plans 8285 and 8206, respectively). The first four building types may require special foundations, therefore check with the manufacturer or an engineer.

Fire Prevention

Where the farm shop (high fire hazard) is included in one end of the machine storage, it should be separated with a 45-minute-rated fire resistant interior partition. Such a partition would consist of 38 x 89 wood studs, 400 oc; 15.6 gypsum wallboard on the shop side (fire side) and 12.5 gypsum wallboard on the machine-storage side; and noncombustible fiberglass or mineral wool insulation between.

Finish the building in non-combustible materials, and hang a charged fire extinguisher near the door.

Ventilation

1. Machine Shed: Moisture build-up often occurs (especially with earth floors). Provide natural ventilation (louvered panels in end walls or rigid ventilators) to prevent moisture accumulating and freezing on uninsulated walls.
2. Workshop: Since this area is primarily used for machinery repair during the off-season, the walls and ceiling should be well insulated and draft free. Space heaters are often used for supplemental heat. Open flame burners require firesafe ducting and chimneys of firesafe masonry or ULC-approved insulated metal. Gases from burners, forges and welding equipment should be removed by mechanical exhaust fans with a suitable hood and non-freezing, anti-draft louvers. Fresh air inlets with back-pressure closing dampers should be installed in the outside walls.

Electrical

1. Power: Suitable service should be installed to handle all the electrical appliances and portable tools. The average farm shop should have at least a 60 ampere service entrance with no fewer than four branch circuits. In addition to the usual 115 volt outlets for lighting and

small appliances, a separate 230 volt circuit with heavy wiring will be needed for an electric welder and for motors larger than ½ horsepower. Where a lot of farm repair and machinery reconstruction is undertaken, it is more efficient to use three-phase service where available. As a safety precaution, make sure that 115 volt appliance plugs cannot be inserted in higher voltage outlets. If the workshop is to be used extensively on a machinery intensive farm, electrical installations must comply with the requirements of the electrical safety code of the province. Special reference should be made to the rural electrical code which may contain specific requirements regarding rural installations. Farmers should be advised to employ an electrical contractor skilled in the techniques of wiring and the installation of electrical equipment.

2. Lighting and Convenience Outlets: Supplement natural lighting with electric lights. In the machinery storage area provide an overhead lighting outlet with reflectors for each 45 m² of floor area, and one 115 volt duplex receptacle for each 10 m of perimeter wall. Install an outside light either on a pole or attached to the building to light the entrance and fuel-servicing area.

In the shop area, provide a general overhead lighting outlet for each 20 m² of floor area. In addition to the general overhead lighting, put floodlights or fluorescent tubes over workbenches and over permanent shop equipment. Locate 115 volt duplex receptables for each 3 m of perimeter wall and 230 volt threaded receptacles at convenient locations for welders and large-horsepower electric appliances.

Use C.S.A. approved electrical fixtures and appliances and protect all circuits, motors and equipment with circuit breakers, fuses and thermal switches.

Doors

Most machinery storage doors are custom made of dimension lumber and covered with the same siding material as used on the building proper. Smaller doors for human use and sectional doors that roll vertically are commercially prefabricated. For roll-track doors, allow an extra 200-300 mm of ceiling height for adequate clearance.

Allow 3.5 to 4.0 m vertical clearance for tractors with roll-over protection safety cabs or for combines. Doors 5 m wide will accommodate most farm equipment. Place doors along one side wall of narrow sheds (up to 10 m) or on both sides of wide buildings (up to 18 m).

Floors

Earth or crushed stone is satisfactory for the machinery storage area if the site is well drained. For multi-use structures and workshop area, a compacted gravel base, 150 µm plastic moisture barrier and 150 mm of concrete is usually recommended. Isolate concrete floor from foundation with an expansion joint.

6.2.7 MANURE STORAGE

Manure production on livestock and poultry farms is a continuous process 365 days per year and, until more acceptable handling procedures become economically feasible, the general practice is to spread it on the land. In the past, when bedding materials were inexpensive and plentiful, dry manure was simply stockpiled and then

disposed on the land when convenient. However, with larger numbers of animals in confinement operations and the high cost of bedding materials, manure is more often handled as a slurry or semiliquid and is frequently accompanied by obnoxious odors.

With the high cost of chemical fertilizers, farmers are giving more consideration to manure as a source of plant nutrients for crop production. This usually means storing the manure until it can be best utilized by a growing crop. For some situations, 5-7 months of storage may be required depending on the length of the winter-spring period. For other cropping systems 12 months storage is desirable.

Before deciding upon the type of storage required, several factors must be considered; these include:

1. Number and kind of livestock
2. State of manure, whether semisolid slurry or liquid
3. Open-top or covered storage
4. Above grade, below grade or in between
5. Length of storage required
6. Manure collection system in the barn
7. Whether to use tank spreader or irrigation system for field application

Other factors such as safety, cost, conservation and environmental pollution must also be considered. Basic design information relating to the quantity of manure produced, the characteristics and quality of the manure, management systems, odor control and alternative uses may be obtained from the *Canada Animal Manure Management Guide* (11) and the *Agricultural Code of Practice for Ontario* (36).

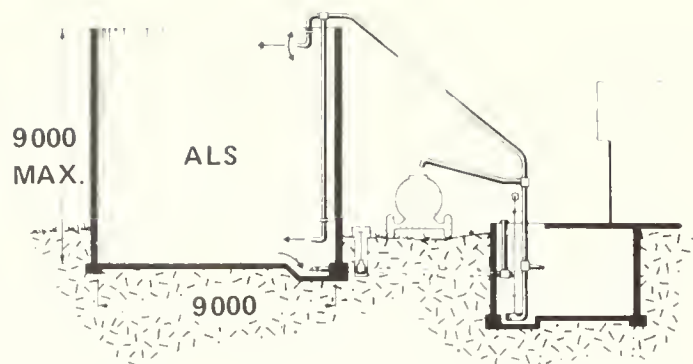
Figure 6.2.44 illustrates eight basic types of manure storages. The four on the left are designed for liquid manure storage, and the four on the right for solid or semisolid manure storage. These were developed by the Canada Plan Service to control pollution and meet the storage requirements for livestock operations across Canada. Detailed plans and descriptive leaflets are available for each design and are identified by the four-digit reference plan number under each illustration.

Manure storages not discussed in this section of the Manual include holding ponds, lagoons, storages built into the livestock housing structure such as pits under slotted floors, poultry cages and oxidation ditches.

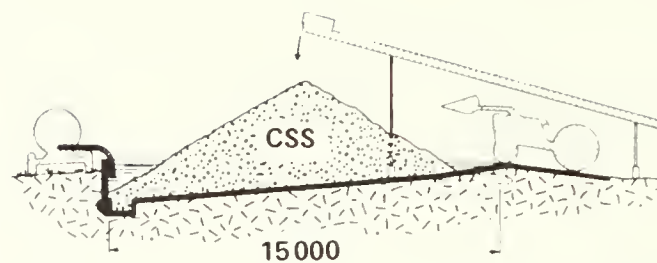
Comparative storage costs (41) for the various basic types of manure storages are given in the cost-volume curves illustrated in Figure 6.2.45. The unit-quantity method and 1975 unit costs for the Ottawa area were used to compute the costs estimates. All storages were assumed to be constructed by contractors hence overhead, profit and taxes are included. However, manure conveyors, underground piping, pumps, loaders and spreaders were not included; fixed components of the storage unit required for use of the manure handling equipment such as entrance ramp, pumping dock, etc. were included.

Obviously the least expensive is the clay-lined manure storage pond "CSP" with pumping dock for liquid manure, and the curbed storage slab "CSS" for stacked manure. The latter, however is limited to storing dry manure or manure with considerable bedding content.

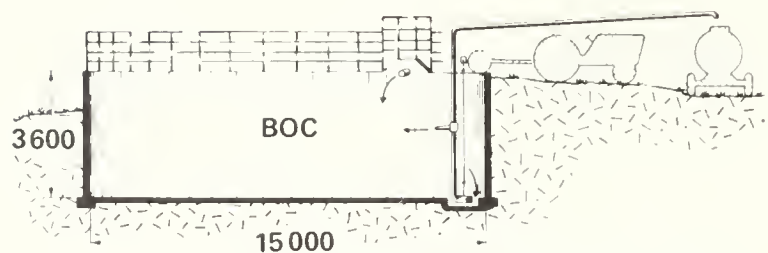
The above-ground liquid manure silo "ALS" type storage is common in Southwestern Ontario and is especially useful in locations with high water table, or shallow soil



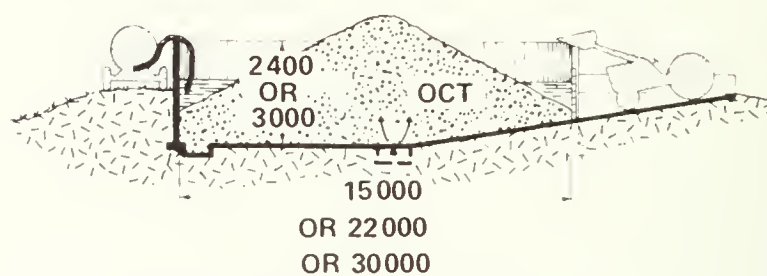
3250 - ABOVE GROUND LIQUID MANURE SILO – TRACTOR PTO PUMP SYSTEM



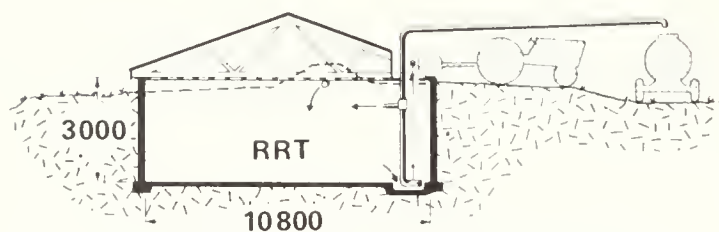
2703 - CURBED STORAGE SLAB FOR STACKED MANURE



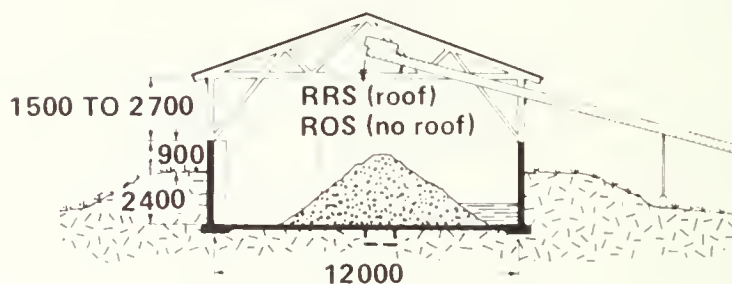
3752 - BELOW - GROUND OPEN CIRCULAR MANURE TANK



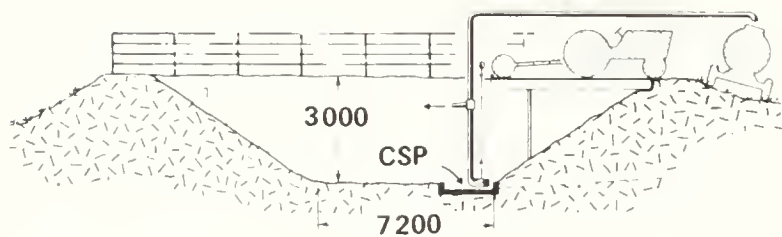
2701 - OPEN CIRCULAR MANURE STORAGE WITH TRACTOR ACCESS



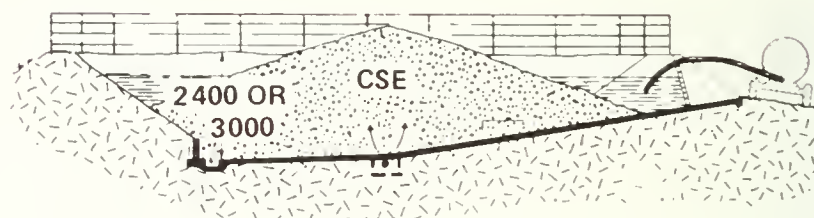
3753 - RECTANGULAR ROOFED MANURE TANK



2705 - RECTANGULAR ROOFED STORAGE FOR SEMI-SOLID MANURE



2702 - CLAY-LINED MANURE STORAGE POND WITH PUMPING DOCK



2704 - CURBED SLAB MANURE STORAGE WITH EARTH BANKS

Figure 6.2.44 Eight basic types of manure storages with descriptive title showing typical methods of filling emptying, also included is the Canada Plan Service reference plan number.

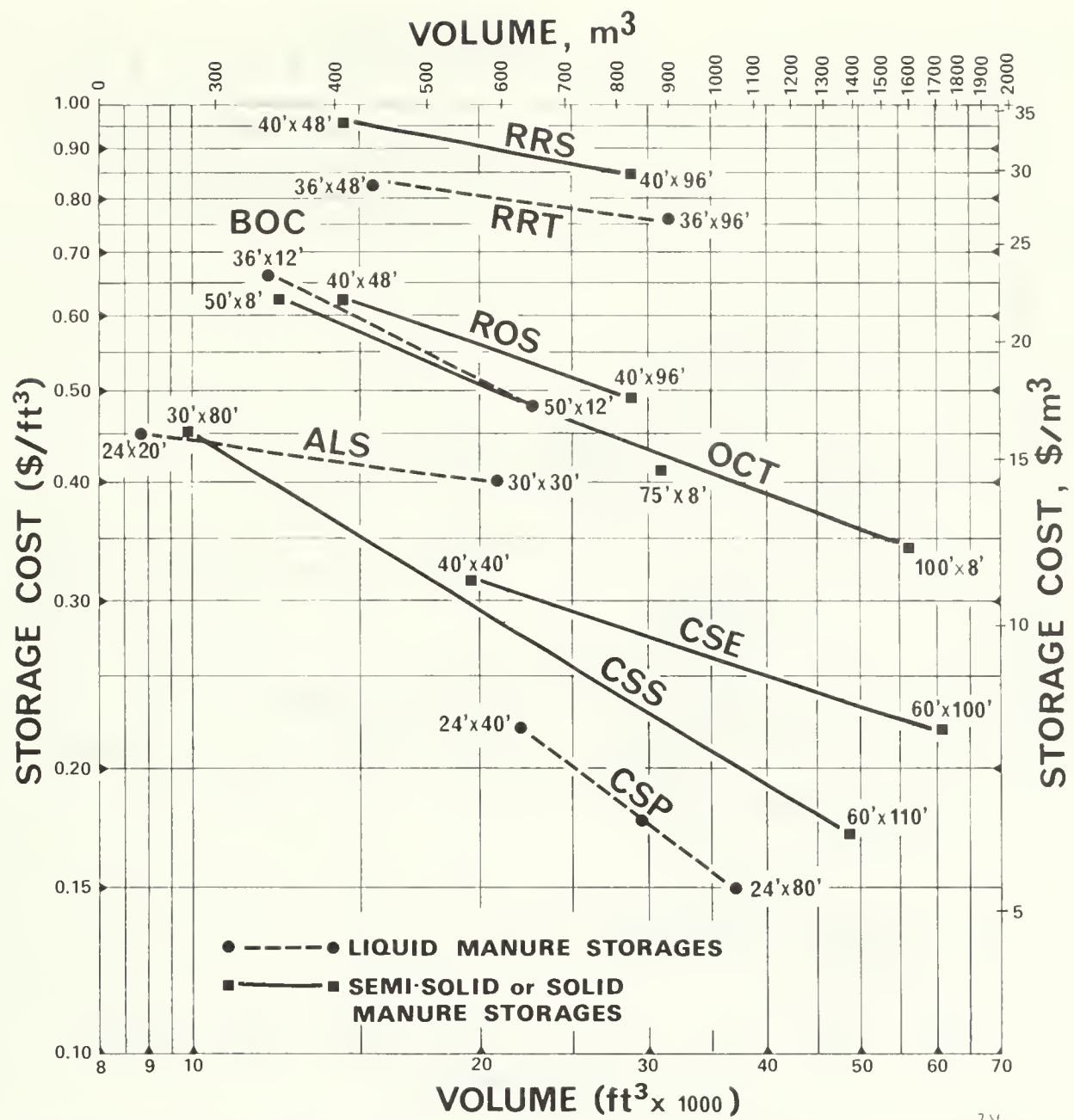


Figure 6.2.45 Cost-volume curves for Canada Plan Service manure storages shown in Figure 6.2.41.

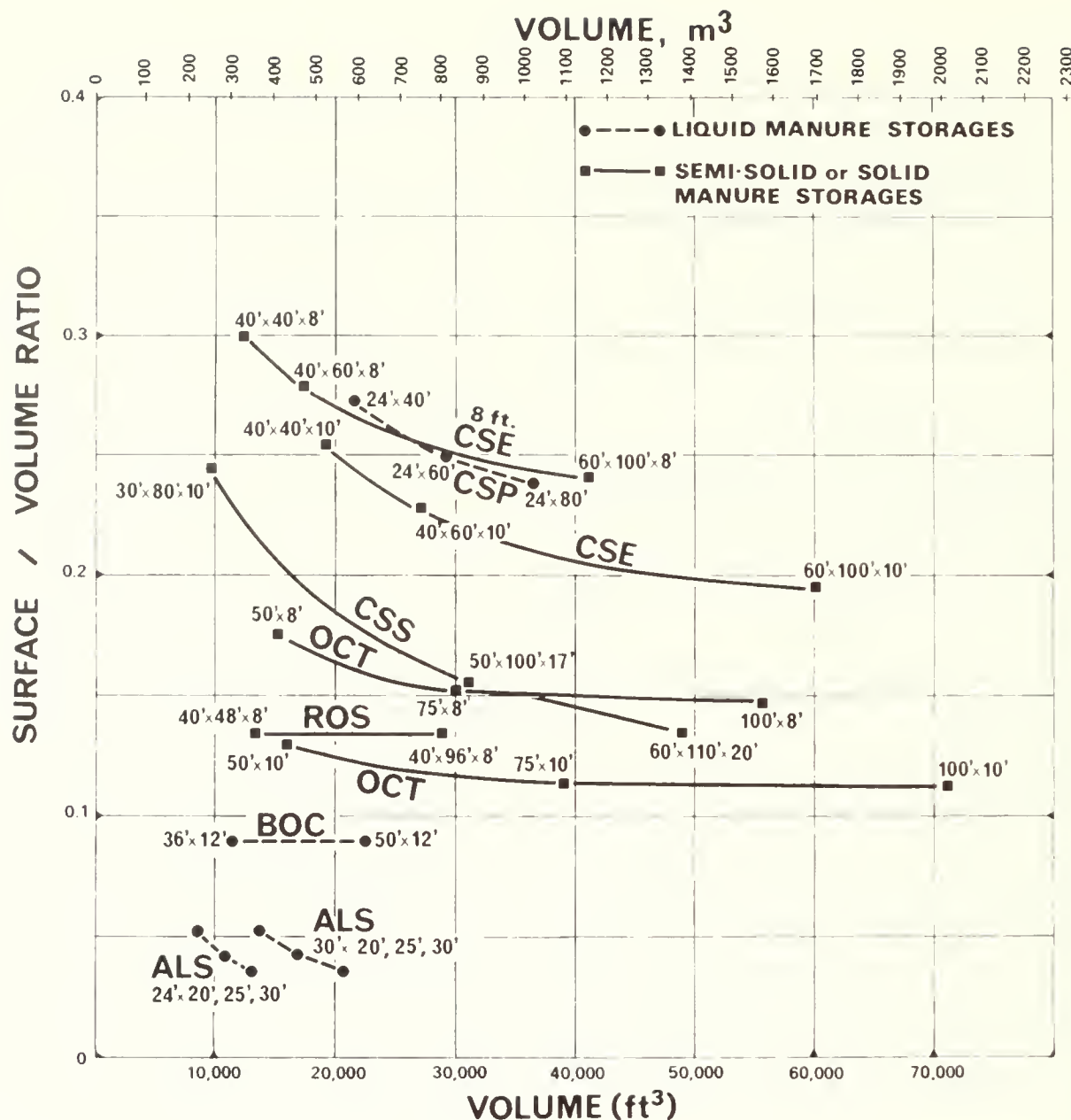


Figure 6.2.46 Surface/volume ratios for Canada Plan Service manure storages shown in Figure 6.2.41.

above bedrock. The floating crust which forms on the liquid surface in these tall silo-type storages provides an effective seal against odors in storage. The extra height also provides some odor dilution. However, the cost of pumping and plumbing equipment required for filling, agitating and emptying can be a disadvantage; hence a least-cost manure storage structure might not necessarily result in a least-cost total manure handling system. For example the below-ground open circular "BOC" manure storage, although a little more expensive, can be filled by gravity and unloaded by a tractor-powered agitator-type pump.

While the construction estimates are based on unit costs for the Ottawa region in 1975, reasonable up-to-date costs can be determined by obtaining the latest building materials and labor index, adjusting this percentage for the geographic region in question and applying it to the cost per cubic metre for the appropriate size and type of manure storage selected in Figure 2.6.45.

The surface/volume ratios shown in Figure 2.6.46, for non-roofed storages, give an indication of how much precipitation a storage will collect in a wet climate, or how much evaporation can take place in a dry climate. Storage types having low surface/volume ratios would be more suitable for wet climates, and types with high surface/volume ratios would be preferred for dry climates.

6.2.8 REFERENCES

1. American Institute of Steel Construction. 1955. Steel construction manual of the AISC. Fifth edition. New York, N.Y.
2. _____. 1960. Aeration of grain in commercial storages. U.S.D.A. Marketing Research Report 178, revised, Nov.
3. _____. 1973. Code of practice - confinement livestock facilities waste management. Alberta Ministry of Environment and Ministry of Agriculture. Agdex 538/710, Sept.
4. _____. Drying shelled corn and small grain with heated air. Agricultural Marketing Service, U.S.D.A. leaflet No. 331.
5. Barre, J.H. and L.L. Sammet. 1950. Farm structures. John Wiley and Sons, Inc. New York.
6. Bodeman, G.R. 1976. Above-ground manure storages: an appraisal. Ann. Mtg. NAR-ASAE. New Brunswick, New Jersey.
7. Bozozuk, M. 1974. Bearing capacity of clays for tower silos. Can. Agr. Eng. 16:1. June.
8. Bruhn, H.D., C.L. Barth and D.C. Staab. 1961. Effect of pelleting on storage design. Paper No. 59-840, ASAE Winter Mtg., Chicago, Illinois.

9. Carter, D.G. and M.D. Farrar. 1943. Redistribution of moisture in soybean bins. *Agr. Eng.* 24:9, 296.
10. Committee on the Agricultural Code of Practice. 1976. *Agricultural Code of practice*. Ontario Ministries of Agriculture and Food, Environment and Housing, Toronto, Ontario.
11. Committee on the Canada Animal Waste Management Guide. 1979. *Canada animal manure management guide*. Pub. 1534, Agr. Canada, Ottawa.
12. Curtis, J.O. Use of hardware cloth in remodelling corn cribs. *Engineering Tips, Farm Buildings No. 9*. Agr. Eng. Dept., U. of Illinois, Urbana, Illinois.
13. Dale, A.C. and R.N. Robinson. 1954. Pressures in deep grain storage structures. *Agr. Eng.* 35:8, 570. August.
14. Darby, D.E. 1977. *Foundations for Tower Silos*. Technical Report No. T732.2, Agriculture Centre, Lethbridge, Alberta.
15. Duffee, F.W., O.I. Berge and E.G. Bruns. 1960. Determining silo size. Preliminary Publication. *Agr. Eng. Dept., U. of Wisconsin, Madison, Wisconsin*.
16. Embry, L.B., et al. 1960. Cattle feeding and digestion trials with alfalfa stored in air-tight and concrete stave silos. *Animal Husbandry Memo Series 61-5*, South Dakota State College, Brookings, South Dakota.
17. Esmay, M.L. and D.B. Brooker. 1955. Lateral pressures in horizontal silos. *Agr. Eng.* 36:10, 651. October.
18. Gross, E.R. 1945. Performance of grain bin floors. *Agr. Eng. Vol. 26:10*, p. 417.
19. Hall, C.W. *Agricultural engineers handbook*. McGraw-Hill Book Co., Toronto, Ontario.
20. Hansen, E.L. et al. 1959. Harvesting, ensiling and feeding high-moisture corn. *Silo News*, Summer. National Silo Association, Louisville, Kentucky.
21. Harder, E.H. 1971. Circular bin arrangements for grain storage. Paper No. 71-213, CSAE Ann. Mtg., Lethbridge, Alberta.
22. Hoglund, C.R., M.L. Esmay, J.S. Boyd and W.W. Snyder. 1958. Economics of bunker and tower silos. *Quarterly Bulletin*. 41:2. Michigan State University, East Lansing, Michigan.
23. Jackson, H.A. and J.R. Lessard. 1977. Effects of moisture content on corn silage density and storage losses in a large tower silo. *Can. Agr. Eng.* 19:57-58.
24. Jofriet, J.C. 1977. Corrosion protection for concrete farm silos. Technical paper no. 77-400. CSAE Ann. Mtg. Guelph, Ontario.
25. McCalmont, J.R., W.C. Krueger and C. Elby. 1946. Pressures and other factors affecting silo construction. *Bulletin 731*. New Jersey Agr. Exp. Sta. November.
26. McCalmont, J.R. and W. Ashby. 1934. Pressures and loads of ear corn in cribs. *Agr. Eng.* 15:4, 123. April.
27. McKenzie, B., N.S. Hadley and J.O. Dunbar. 1956. Low cost grain handling from field to feed lot. *Purdue University Mimeo E.C.-146*. Purdue University, Lafayette, Indiana. January.
28. McLaughlin, N.B., D.B. Wilson and D.M. Bowden. 1978. Effect of a plastic cover on dry matter losses from a horizontal silo. *Can. Agr. Eng.* 20:1-4.
29. Moore, L.A. Problems and recent improvements in the preparation and use of grass silage. U.S.D.A. Dairy Cattle Research Branch, ARS 44-23.
30. Neubauer, L.W. and H.B. Walker. 1961. *Farm building design*. Prentice-Hall, Inc., Englewood Cliffs, N.J.
31. O'Rourke, C.E. 1940. *General engineering handbook*. Section edition. McGraw-Hill Book Co. Inc. New York.
32. Portland Cement Association. 1958. *Farm silos of cast-in-place concrete*. Portland Cement Association, 33W Grand Ave., Chicago, Illinois.
33. Pos, J. and A.H. Singleton. 1975. Comp-O-Bilt, pre-fabricated components for farm buildings. Paper No. 75-217., CSAE Ann. Mtg., Brandon, Manitoba.
34. Shove, G.C. Aerating farm-stored grain. Circular 840. U. of Illinois, Urbana, Illinois.
35. Stahl, B.M. 1946. Storage performance of grain bin floors *Agr. Eng.* 27:8, 357.
36. Standing Committee on Farm Buildings. 1977. *Canadian farm building code*. NRCC No. 15564. National Research Council, Ottawa, Ontario.
37. Technical Committee on Engineering Design in Wood. 1980. *Code for engineering design in wood*. CSA Standard 086-M. Canadian Standards Assoc. 178 Rexdale Blvd., Rexdale, Ontario, Canada.
38. Theakston, F.H. 1978. Determination of lining material to prevent corrosion of steel grain storage bins. Tech. Report No. 126-43. School of Engineering, U. of Guelph.
39. Turnbull, J.E., H.A. Jackson and D. Lowe, 1977. Reinforced extended ring foundations for top-unloading concrete tower silos. *Can. Agr. Eng.*, 21:2, Dec. pp. 111-116.
40. Turnbull, J.E. and H.A. Jackson. 1975. Procedure for design of diaphragm ceilings for farm buildings. Contr. No. 459, Eng. & Stat. Res. Inst., Agriculture Canada. Ottawa, K1A 0C6.
41. Turnbull, J.E., P.A. Phillips and F.R. Hore. 1977. Design concepts and construction costs of eight different manure storages. *Can. Agr. Eng.* 19:65-70.
42. Yu, W.W. and J.S. Boyd. 1961. Progress report of three year's work to determine pressures in tower silos. 1961 Proceedings of Michigan Silo Conference, Michigan State University, East Lansing, Michigan.

LIBRARY / BIBLIOTHEQUE



AGRICULTURE CANADA OTTAWA K1A 0C5

3 9073 00022033 7

